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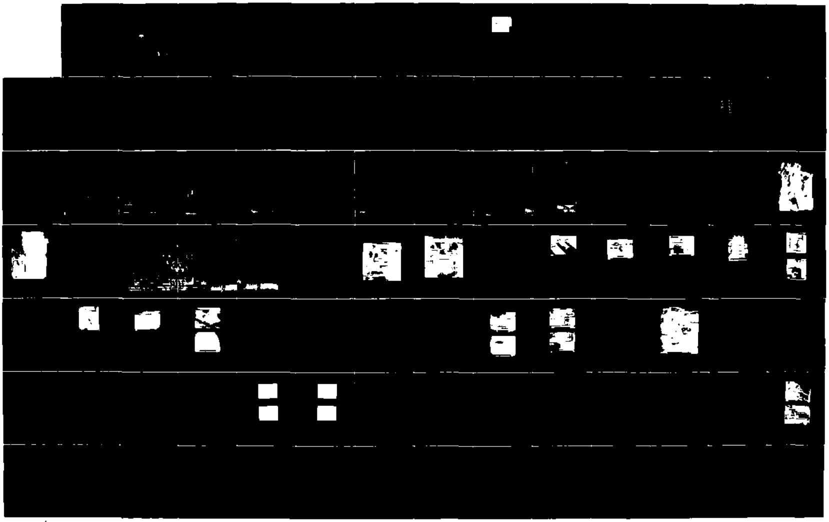

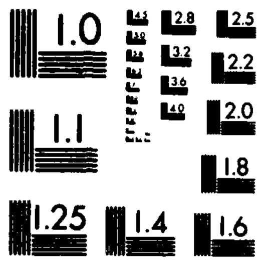

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FABRICATION AND TESTING OF LIGHTWEIGHT HYDRAULIC SYSTEM SIMULATOR HARDWARE — PHASE II

AD-A169 884

Rockwell International
North American Aircraft Operations
4300 East Fifth Avenue
P.O. Box 1259
Columbus, Ohio 43216

JANUARY 1986

FINAL REPORT FOR PERIOD 15 MAY 1980—15 NOVEMBER 1985

Prepared For

NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, DC 20361

NAVAL AIR DEVELOPMENT CENTER
Aircraft and Crew Systems Technology Directorate
Warminster, PA 18974

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The Lightweight Hydraulic System (LHS) Advanced Development Program is a multi-phase investigation of the concept of using an 8000 psi operating pressure level to achieve smaller and lighter weight hydraulic components than those used in aircraft with conventional 3000 psi systems. This report presents the results of Phase II in which a full scale A-7E 8000 psi dual system hydraulic simulator was fabricated and tested. Tests conducted were proof pressure, system integration, baseline, dynamic performance, and 600 hours of endurance cycling. No major technological problems were encountered. Four flight control actuators accumulated over 3,000,000 cycles; one pump accumulated over 1000 hours of operation (Phase I + Phase II). Hydraulic system math models were corroborated by test data. A weight and space analysis update projected 33.1% and 36.3% savings, respectively, over an equivalent 3000 psi system. A study of simulator operating experience indicated a 23% improvement in reliability over a comparable 3000 psi system. An additional 600 hours of simulator endurance cycling are scheduled for completion in FY '86.

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EXECUTIVE SUMMARY

1.0 PURPOSE OF THE PROGRAM

Power requirements of hydraulic systems in military aircraft have risen steadily from a few horsepower during World War II to over 1000 horsepower in the current B-1B bomber. Advanced tactical fighters in the 1990's are expected to have large increases in hydraulic power levels over comparable existing aircraft yet have less space available for installation of hydraulic components. Significant improvements must therefore be made in hydraulic system energy management and in reducing component weight and size. The multi-phase Lightweight Hydraulic System (LHS) Advanced Development Program is an investigation of the concept of using an 8000 psi operating pressure level to achieve smaller and lighter weight components than those used in conventional 3000 psi systems.

2.0 BENEFITS TO THE NAVY

The LHS Advanced Development Program is an assessment of the advantages of using an 8000 psi operating pressure level instead of the standard 3000 psi level. The benefit goals established for 8000 psi lightweight hydraulic systems over conventional 3000 psi systems are:

Weight	30% reduction
Volume	40% reduction
MFHBF	15% improvement
MMH/FH	15% improvement

3.0 BACKGROUND INFORMATION

The Navy began an Exploratory Development Program in 1966 to study the practicality and potential benefits of using operating pressure levels higher than 3000 psi. The program included a feasibility study, component development and testing, selection of an optimum operating pressure level, laboratory system testing, and brief flight testing. The program established that: 1) 8000 psi hydraulic systems are practical, and 2) overall weight and volume can be reduced (on a retrofit basis) up to 30% and 40%, respectively, for systems delivering more than approximately 100 horsepower. Future aircraft hydraulic systems may show even greater benefits in weight and space savings using 8000 psi technology.

The development of a full scale lightweight hydraulic system was undertaken to demonstrate and validate 8000 psi technology in a system designed for installation in an A-7E test bed aircraft. Objectives of the full scale LHS Development Program were:

- o Re-design the A-7E flight control hydraulic and actuation systems to operate at 8000 psi.
- o Demonstrate 8000 psi system reliability by long term endurance testing.
- o Assess the effects of utilizing 8000 psi technology on component weight & volume and R&M.

The full scale Lightweight Hydraulic System Development Program was scheduled to be performed in three phases:

Phase I Design, fabricate, and test 8000 psi components. (Documented in Report NADC-77108-30, Design, Development, and Evaluation of Lightweight Hydraulic System Hardware - Phase I, dated January 1981)

Phase II Fabricate full scale hydraulic simulator. Conduct performance and endurance tests.

Phase III Install 8000 psi hydraulic system in an A-7E aircraft. Conduct flight test program.

This report covers Phase II

4.0 PHASE II PROGRAM OBJECTIVE

The primary objective in Phase II was to substantiate the acceptability of LHS components for flight testing on an A-7E aircraft. This was done by demonstrating that the LHS hardware met design requirements and was validated by:

- o Confirming component performance
- o Determining system pressure, flow, and temperature characteristics
- o Demonstrating system stability, response, and control
- o Verifying component/system endurance capabilities
- o Providing data for R&M determinations
- o Substantiating math models
- o Providing data to verify predicted weight and volume savings

5.0 PHASE II SUMMARY

5.1 HYDRAULIC SYSTEM DESIGN

Hydraulic circuitry design was completed in Phase I. The A-7E systems were reconfigured from three independent power control systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system. Primary control surface actuators were aileron, spoiler/deflector, rudder, and unit horizontal tail (UHT). Secondary flight controls include a speed brake and wing leading edge flaps. The automatic flight control system (AFCS) has three actuators: roll, pitch, and yaw.

All A-7E flight control actuators were fabricated except the RH aileron, RH spoiler/deflector, RH leading edge flaps, and two AFCS units. These actuators were not procured because of program funding limitations. Initial testing was conducted with a one pump system. Subsequent funding permitted fabrication of a two system configuration. The aileron, rudder, LH UHT, yaw AFCS, and speed brake actuators were fabricated and tested in Phase I.

The LHS actuators were designed for the same end attach points, kinematics, load, stroke, and rate requirements as their counterpart 3000 psi actuators. Conventional design techniques and fabrication procedures were employed for all the test units. The 8000 psi pumps were a typical variable delivery in-line piston design with several unique features to optimize performance at 8000 psi.

5.2 SIMULATOR DESIGN

The LHS simulator is a steel structure with aircraft hydraulic component installations designed to represent a full scale A-7E 8000 psi flight control system. Modular design was employed to facilitate fabrication and permit testing of individual actuators. Load/stroke conditions imposed on each actuator were based on original A-7E design requirements. Transmission line lengths, routing, and fittings were as close as practical to those anticipated in the aircraft.

5.3 SIMULATOR TESTS

Proof Pressure. Two types of proof tests were conducted on the newly fabricated systems. Pressure lines and fittings alone were proofed at 16,000 psi. Then with all components installed, the total system was proofed at 12,000 psi.

System Integration. Initial operation of the simulator was accomplished using a planned start-up procedure. Hydraulic fluid clean-up and actuator rigging were performed first. A hydraulic resonance survey and simulator operating stability tests were then conducted. Maximum pump ripple found was 300 psi peak-to-peak; the maximum allowable is 400 psi peak-to-peak.

Lightweight Hydraulic System Simulator

Baseline. Tests were performed to determine the range and distribution of simulator fluid temperatures, pressures, and flows. Stabilized temperatures resulting from operation with pump suction fluid maintained at +200°F were recorded. Pump case drain fluid temperature never exceeded +260°F. Pump discharge flow during simulator cycling varied from 1.2 to 5.4 gpm; pump case flow ranged from 1.1 to 1.3 gpm. Internal leakage of all actuators and valves totaled 0.8 gpm with the actuators at null.

Dynamic Performance. Pressure dynamics occurring in the discharge line near the pump were surveyed. The maximum pressure ripple found was 300 psi peak-to-peak. Information developed in this investigation was used to support math model testing.

Measurements were taken in the pressure and return systems to verify that pressure transients resulting from the operation of actuators and solenoid valves did not exceed the design limit of 9600 psi. All pressure peaks were acceptable except at the AFCS yaw actuator where an 11,700 psi surge occurred when a shut-off valve was energized. The surge was eliminated by installing a restrictor.

Simulator tubing vibration was measured to verify that stress levels were satisfactory. Sixteen locations were surveyed. All vibration was well below maximum acceptable amplitudes.

Actuator frequency response was determined under both load and no-load conditions for three modes of operation. Overdamped operating characteristics were observed. The various operating modes had only minor effects on performance.

Endurance. This test was conducted to demonstrate that component performance and reliability were satisfactory for long periods of operation. A typical 2 hour flight mission was simulated and repeated until a total of 600 hours of operation were accumulated. Component performance checks were made at 150 hour intervals. Selected actuators were disassembled at these times and examined for wear.

Actuator load/stroke magnitude and cycle distribution were as follows:

Load/Stroke	Cycling Rate	Total Cycles
2%	3 Hz	5400
10%	1 Hz	900
50%	0.25 Hz	375
100%	0.12 Hz	72
		6747/2 Hours

LHS component performance summaries given below include Phase I hours and cycles.

Pumps. Operating time totals were: FC-1, 1043 hours; FC-2, 543 hours; "spare", 221 hours. Pump overall efficiency was marginal; heat rejection was 20% higher than the design goal of 300 BTU/min. Pump endurance characteristics were good except for the pintle bearings which were under-sized. A re-designed pump currently under test is expected to resolve the performance deficiencies.

Actuators. Four actuators have completed approximately 3,000,000 cycles. The endurance characteristics of all actuators were considered satisfactory, and further cycling is planned to accumulate an additional 2,000,000 cycles during 600 more hours of operation.

Minor Components. Although some quality control and design deficiencies were encountered, in general, the performance of all minor components such as check valves, relief valves, and restrictors was considered satisfactory. Coil tubing used in the spoiler/deflector installation will require additional development effort.

Ground Support Equipment. An AHT-63 portable hydraulic test stand was converted to operate at 8000 psi by replacing 3000 psi components with 8000 psi components. The GSE was operated a total of 13.0 hours during simulator demonstrations and tests. Performance was satisfactory except for heat dissipation which was marginal. Efforts are currently in progress to increase the heat removal capacity.

5.4 MATH MODEL

Hydraulic system dynamic analysis was conducted on the LHS simulator using a computer program developed by the Air Force. Two types of analyses were performed:

- o Prediction of locations, amplitudes, and frequencies of standing wave oscillating pressures.
- o Prediction of hydraulic system response to sudden changes in flow demand resulting in pressure disturbances throughout the system.

FC-1 system was modeled for the frequency response analysis. The predictions were verified near the pump using test data generated by a clamp-on pressure transducer and spectrum analyzer. Correlation of math model results with the measured test data was considered good. All pressure ripple amplitudes were less than the maximum allowable ± 200 psi. The pressure peak observed in the rudder actuator control system was used to corroborate the transient analysis program. The math model prediction was considered excellent.

5.5 SYSTEM WEIGHT AND SPACE ANALYSIS

A major objective of the LHS program was to verify the projected 30% weight and 40% volume reductions achieved by using an 8000 psi operating pressure level instead of 3000 psi. Weight and space savings calculated in Phase I were updated to reflect actual hardware weight measurements taken in Phase II. The updated weight and space savings were:

Total weight of EQUIVALENT 3000 psi system	644.4 lb
Total weight of 8000 psi system	431.3 lb
Weight reduction	213.1 lb
Weight savings	33.1 %
Total volume of EQUIVALENT 3000 psi system	8173 in^3
Total volume of 8000 psi system	5207 in^3
Volume reduction	2966 in^3
Space savings	36.3 %

5.6 RELIABILITY & MAINTAINABILITY ASSESSMENT

The R&M assessment was based primarily on data accumulated from LHS simulator mission/profile testing. R&M goals were to achieve a 15% improvement over current fleet experience with the A-7E aircraft. A reliability growth trend analysis was performed using the laboratory data, and a failure-modes-and-effects analysis was made to determine design improvement requirements.

The data base developed in this program substantiated that 8000 psi technology does not compromise the reliability or maintainability of an aircraft hydraulic system. Experience gained from LHS simulator testing indicated a potential improvement in reliability of 23% over a comparable 3000 psi system. The reduced failure rate translates to an 18% reduction in maintenance man-hours. These figures exceed the R&M improvement goal of 15%.

5.7 LHS SPECIFICATIONS

A total of 34 preliminary specifications covering system and component requirements for 8000 psi lightweight hydraulic systems were prepared in Phase I. Ten specifications were updated in Phase II based on laboratory test experience. One new specification was written.

6.0 CONCLUSIONS

Major advances toward the goals of the LHS program were accomplished in Phase II. A full scale, dual system 8000 psi hydraulic simulator was fabricated and 600 hours of endurance testing were completed satisfactorily. Six hundred additional hours of cycling are planned. R&M improvement and weight and space saving objectives were validated. The practicality of the 8000 psi lightweight hydraulic system concept was demonstrated conclusively in Phase II. Full scale flight testing is now the logical next step.

7.0 RECOMMENDATIONS

The LHS advanced development program should proceed by conducting the planned Phase III flight tests using an A-7E test bed aircraft. Additional effort should be directed toward support of 8000 psi technology for next generation aircraft. Recommended tasks are:

- Use the LHS simulator as a means to evaluate emerging technologies such as rotary actuators, PEEK seals, and energy efficient concepts.
- Conduct a full qualification test on a re-designed 8000 psi pump.
- Conduct full qualification tests on 8000 psi tubing/fittings.
- Develop coil tube installation design guidelines.
- Conduct extreme temperature tests on LHS simulator components.

PREFACE

This report documents a development program conducted by Rockwell International Corporation, North American Aircraft Operations, Columbus, Ohio, under Contract N62269-80-C-0261 with the Naval Air Development Center, Warminster, Pennsylvania. Technical direction was administered by Mr. J. Ohlson, Head, Materials Application Branch, Aircraft and Crew Systems Technology Directorate, Naval Air Development Center (6061), and Mr. S. Hurst, Assistant Technology Administrator, Naval Air Systems Command (AIR-340C).

This report presents the results of Phase II of a program to design, fabricate, and test a full scale 8000 psi Lightweight Hydraulic System in a ground simulator and A-7E flight test aircraft. This work is related to tasks performed under Contracts NOw-65-0567-d, N00019-68-C-0352, N00156-70-C-1152, N62269-71-C-0147, N62269-72-C-0381, N62269-73-C-0700, N62269-74-C-0511, N62269-75-C-0422, N62269-76-C-0254, N62269-78-C-0005, and N62269-78-C-0363.

The project engineer for Phase II of the LHS Advanced Development Program was Mr. W. Bickel. Acknowledgement is given to the following engineers for their contributions to this report.

Mr. W. Andrews	Math Model
Mr. E. Kauffman	R&M Assessment
Mr. L. Grieszmer	LHS Specifications and Weight & Space Analysis

Appreciation is extended to the many individuals who provided helpful support and constructive criticism of the program; in particular, Mr. S. Hurst of the Naval Air Systems Command, Mr. J. Ohlson and Mr. J. Dever of the Naval Air Development Center, Mr. F. Perian of Vickers Corporation, Mr. R. Olsen and Mr. K. Fling of Vought Corporation, Dr. D. Uhr of Pall Corporation, and Mr. L. Biafore and Mr. E. Culp of Rockwell International.

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

The Navy began an Exploratory Development Program in 1966 to study the practicality and potential benefits of using an operating pressure level higher than 3000 psi. The program included a feasibility study, component development and testing, selection of an optimum operating pressure level, laboratory system testing, and brief flight testing, references 1 through 11. The program established that: 1) 8000 psi hydraulic systems are practical, and 2) overall weight and volume can be reduced (on a retrofit basis) up to 30% and 40%, respectively, for hydraulic systems delivering more than approximately 100 horsepower. Future aircraft hydraulic systems may show even greater benefits in weight and space savings using 8000 psi technology.

1.2 PROGRAM OBJECTIVES

The development of a full scale lightweight hydraulic system was undertaken to validate and demonstrate 8000 psi technology in a system designed for installation in an A-7E test bed aircraft. Objectives of the full scale LHS Development Program were:

- o Re-design the A-7E flight control hydraulic and actuation systems to operate at 8000 psi.
- o Demonstrate 8000 psi system reliability by long term endurance testing.
- o Assess the effects of utilizing 8000 psi technology on component weight & volume and reliability & maintainability

Ultimate benefit goals established for 8000 psi lightweight hydraulic systems over conventional 3000 psi systems were:

Weight	30% reduction
Volume	40% reduction
MFHBF	15% improvement
MMH/FH	15% improvement

The full scale Lightweight Hydraulic System Development Program was scheduled to be performed in three phases:

- Phase I — Design, fabricate, and test 8000 psi components (see reference 11).
- Phase II — Fabricate full scale hydraulic simulator. Conduct performance and endurance tests (reported herein).
- Phase III — Install 8000 psi hydraulic system in an A-7E aircraft. Conduct flight test program.

1.3 PHASE I SCOPE OF WORK

The scope of work completed in Phase I and documented in reference 11 is summarized below:

- Task I — Design the 8000 psi flight control system to be tested in an A-7E aircraft.
- Task II — Prepare preliminary military specifications for 8000 psi components and systems.
- Task III — Design 8000 psi components. Fabricate selected components.
- Task IV — Conduct component testing including seal development, valve erosion, acceptance, endurance, impulse, and compatibility.
- Task V — Assess R&M from test program data.
- Task VI — Design ground simulator. Design and fabricate selected subsystem modules.
- Task VII — Develop preliminary math model for test system.
- Task VIII — Verify projected weight and space savings to be achieved.
- Task IX — Determine GSE interface requirements and make recommendations for equipment to be utilized in follow-on phases.

1.4 PHASE II SCOPE OF WORK

The scope of work in Phase II was as follows:

Task		Description	Page
Task	I	Procure major 8000 psi components	48
Task	II	Procure actuator load modules	38
Task	III	Procure minor 8000 psi components	48
Task	IV	Procure modification of AHT-63 GSE	111
Task	V	Fabricate simulator structure	29
Task	VI	Fabricate simulator hydraulic systems	35
Task	VII	Fabricate simulator instrumentation/ control system	54
Task	VIII	Prepare simulator test plan	reference 12
Task	IX	Conduct simulator tests including: proof pressure, system integration, baseline, dynamic performance, math model, GSE, and endurance	59
Task	X	Update Phase I math model using Phase II data	112
Task	XI	Update Phase I weight and space analysis using Phase II data	129
Task	XII	Update Phase I R&M analysis using Phase II data	132
Task	XIII	Update LHS specifications using Phase II information	145
Task	XIV	Piston seal endurance test (conducted by Vought Corporation)	addendum
Task	XV	Develop an 8000 psi check valve pump (fabricated by Hydrodyne)	addendum
Task	XVI	Conduct 600 additional hours of simulator endurance testing	addendum

The test plan and specifications developed in Tasks VIII and XIII were submitted to the Navy Project Office under separate cover, references 12 and 13, respectively. The results of Tasks XIV, XV, and XVI will be documented in an addendum to this report.

1.5 SUBCONTRACTING

Fourteen suppliers were awarded subcontracts to support the LHS Advanced Development Program in Phase II. Two firms provided major support: Vought Corporation, Dallas, Texas, and Vickers, Incorporated, Jackson, Mississippi.

Vought Corporation is a prime manufacturer of military aircraft and provided important support in several areas:

- o Supplied technical information on the A-7E
- o Designed and fabricated flight control actuators and load modules
- o Conducted acceptance and limited endurance testing of actuators
- o Conducted piston seal endurance tests

Vickers, Incorporated is a major manufacturer of aircraft hydraulic pumps. This firm developed the variable delivery pumps used to power the 8000 psi test systems.

2.0 HYDRAULIC SYSTEM DESIGN

2.1 A-7E AIRCRAFT BASELINE SYSTEM

The A-7E hydraulic systems operate at 3000 psi and are designed to MIL-H-5440 Type II (-65 to +275°F) requirements. Primary flight control surfaces are powered by dual tandem hydraulic actuators -- aileron, spoiler/deflector, rudder, and unit horizontal tail (UHT). Each actuator is pressurized by two of three independent hydraulic systems as shown on Figure 1. If one system fails, the other two continue to supply power. Secondary flight controls include the speed brake and wing leading/trailing edge flaps. Dual parallel automatic flight control system (AFCS) actuators are provided for the roll, pitch, and yaw axes. System pumps are pressure compensated, variable delivery axial piston designs. MIL-H-5606 hydraulic fluid is supplied to each pump by an airless, bootstrap type reservoir.

2.2 A-7E LIGHTWEIGHT HYDRAULIC SYSTEM

The A-7E hydraulic circuitry was reconfigured from three independent systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system, Figure 2. A detail schematic diagram of FC-1 and FC-2 is presented as Figure 3. This work was done in Phase I, reference 11.

All A-7E flight control actuators depicted on Figure 3 were fabricated except the RH aileron, RH spoiler/deflector, RH leading edge flaps, and two AFCS units. These actuators were not procured because of program funding limitations. Initial testing was conducted with a one pump system, Figure 4. Subsequent funding permitted fabrication of a two system configuration which was used for all remaining tests, Figure 5. Previously built seal test fixtures, reference 10, were installed in the RH aileron location at the 300 hour point of cycling. The fixtures provided pump loading and an opportunity to evaluate additional dynamic seals.

The LHS simulator includes nearly every type of component normally used in aircraft hydraulic systems (see Section 3.3). All test components were located on the simulator in relative positions representative of an A-7E installation. Tubing lengths and routing were as close as practical to those anticipated in the A-7E. Pressure (8000 psi) tubing was titanium. Pressure line fittings were both permanent and separable; the separable fittings were a lip-seal design. Return lines were primarily aluminum with MS flareless type fittings for cost effectiveness. Static boss seals were conventional MS28778. The hydraulic fluid was per specification MIL-H-83282A/B. Fluid volume in FC-1 and FC-2 systems was 3.2 gallons (each). Fluid filtration was 5 microns absolute.

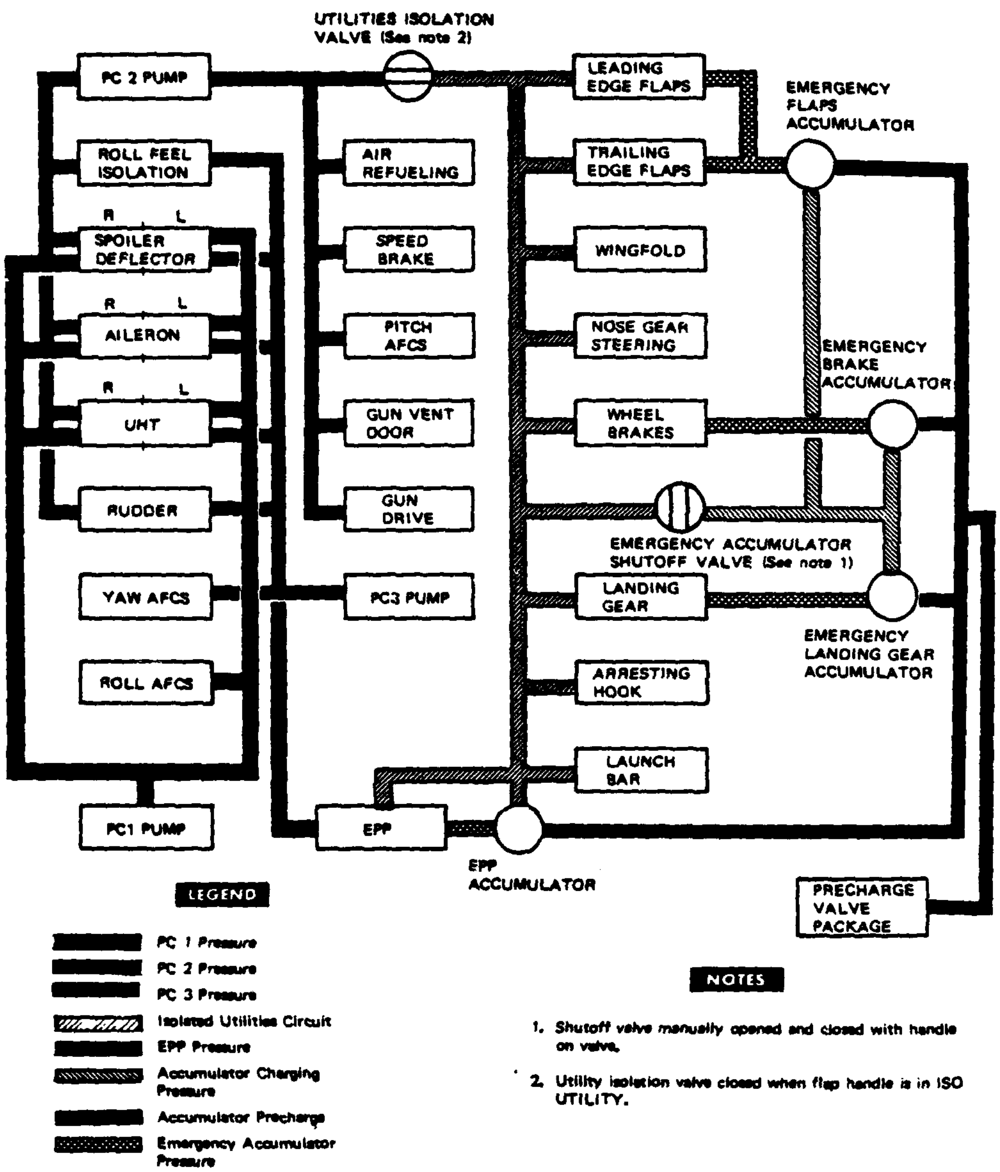


FIGURE 1. A-7E hydraulic system

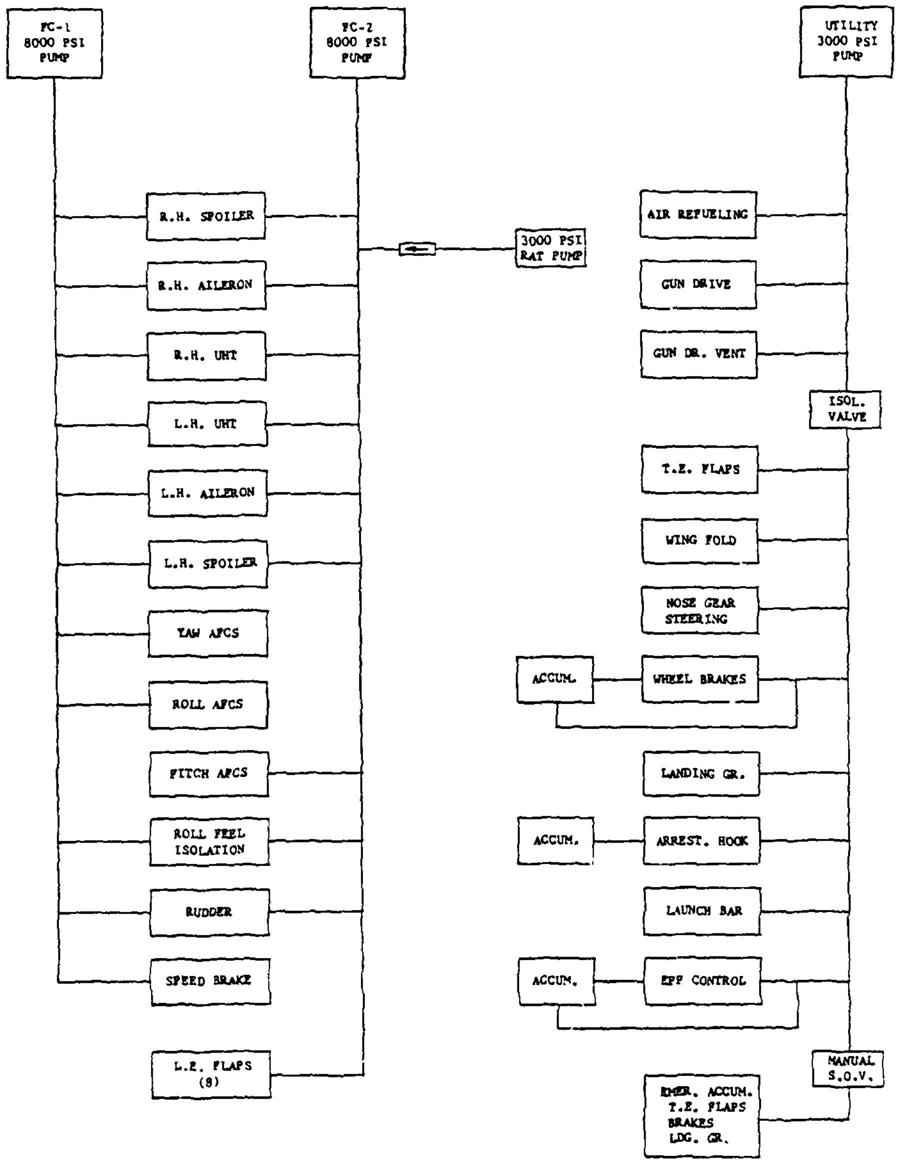
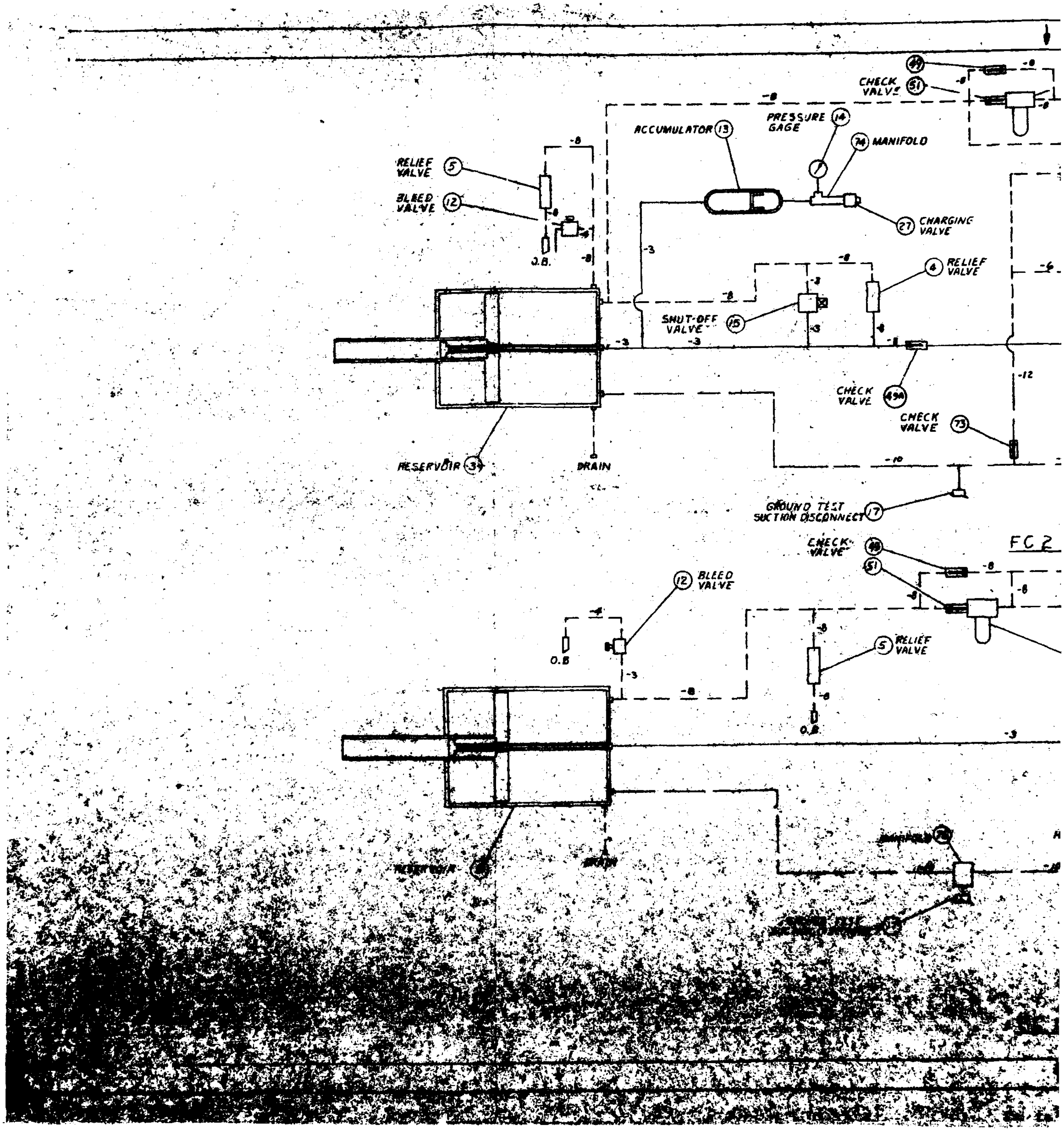


FIGURE 2. A-7E lightweight hydraulic system

LHS proof, burst, and surge design factors, expressed as a percent of operating pressure, are listed below.

	Proof Pressure	Burst Pressure	Max. Allowable Pressure Surge
Tubing, Fittings, Hoses	200%	300%	120%
Components, i.e., Actuators Valves, Disconnects, Etc.	150%	200%	120%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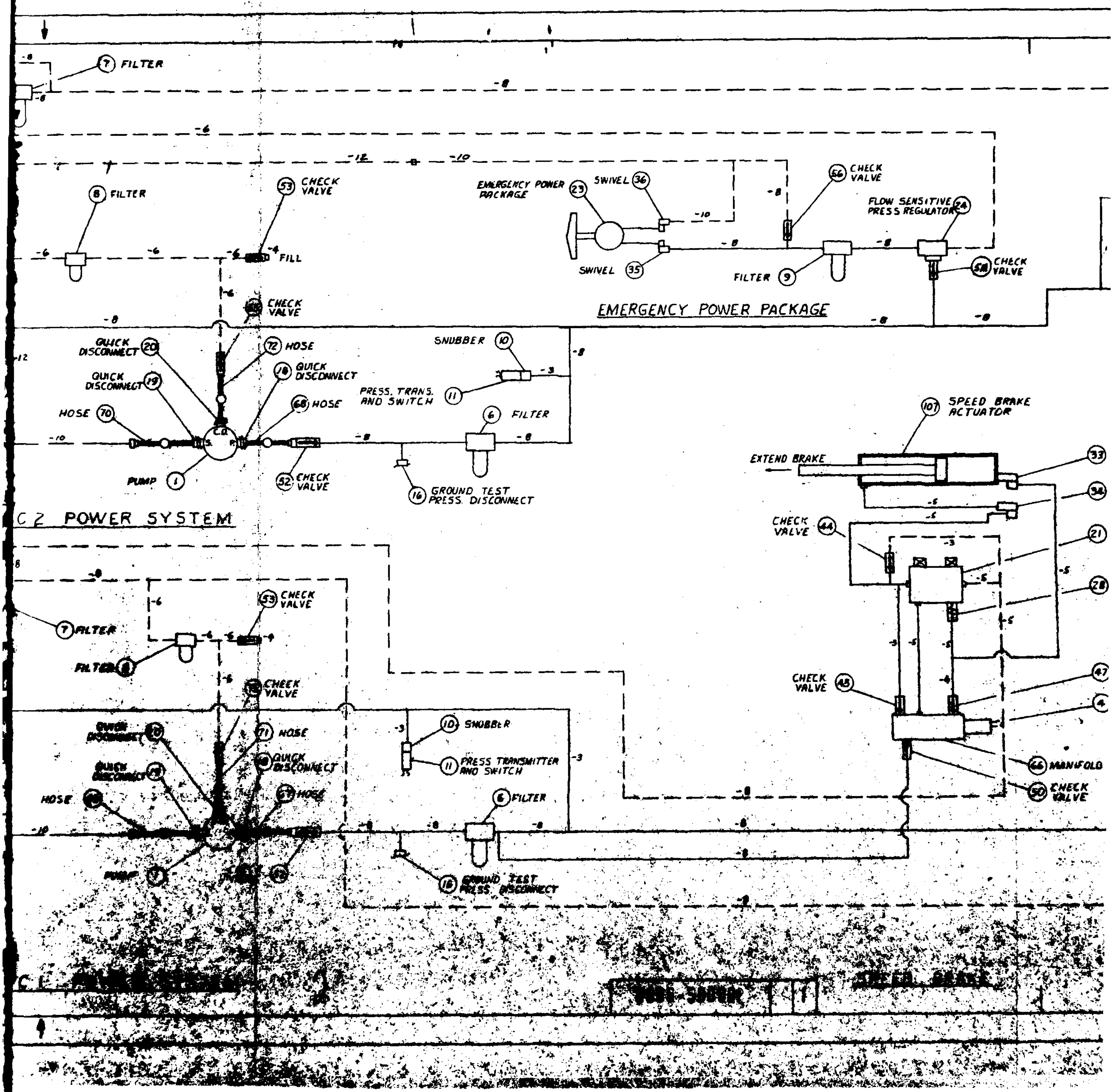

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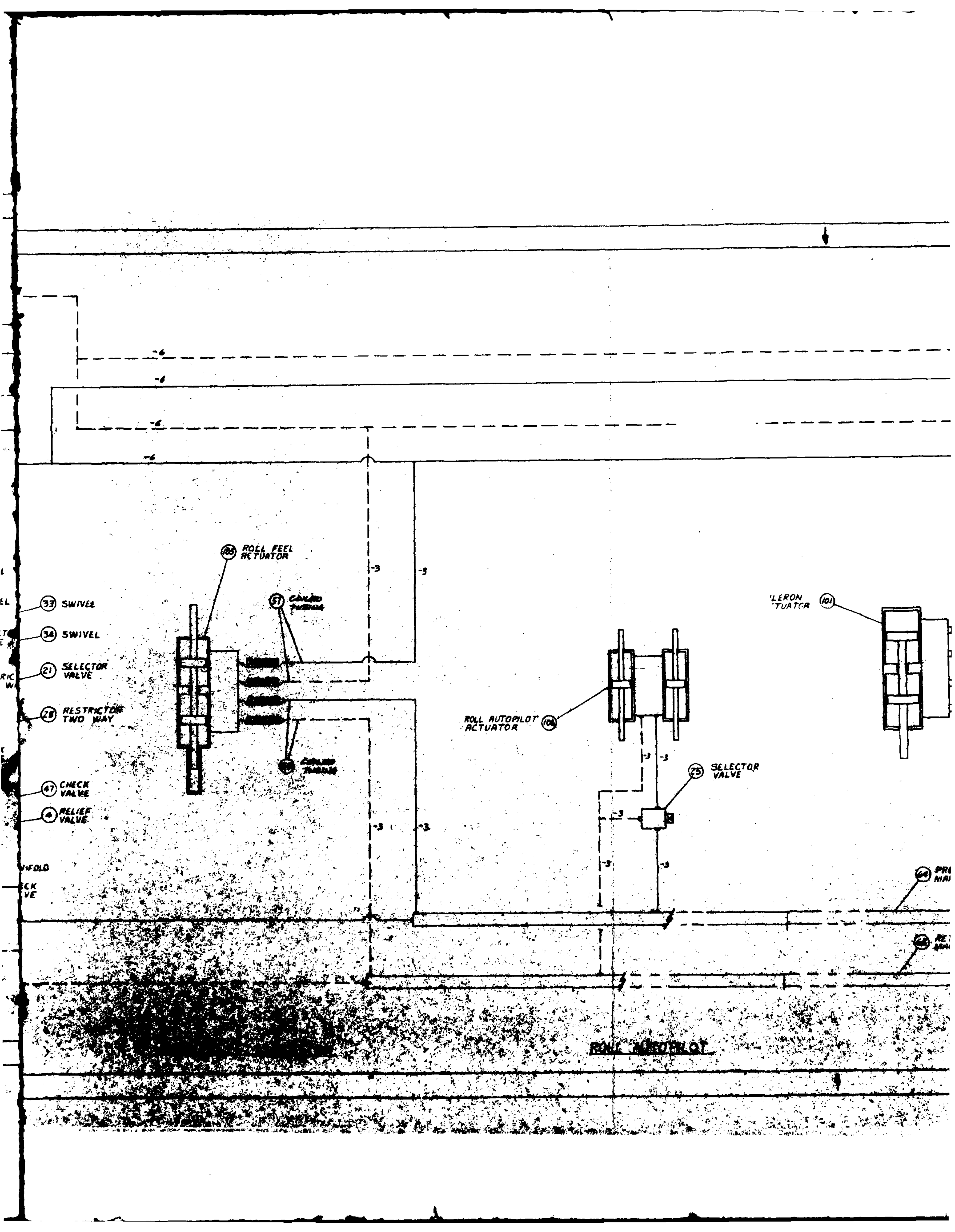
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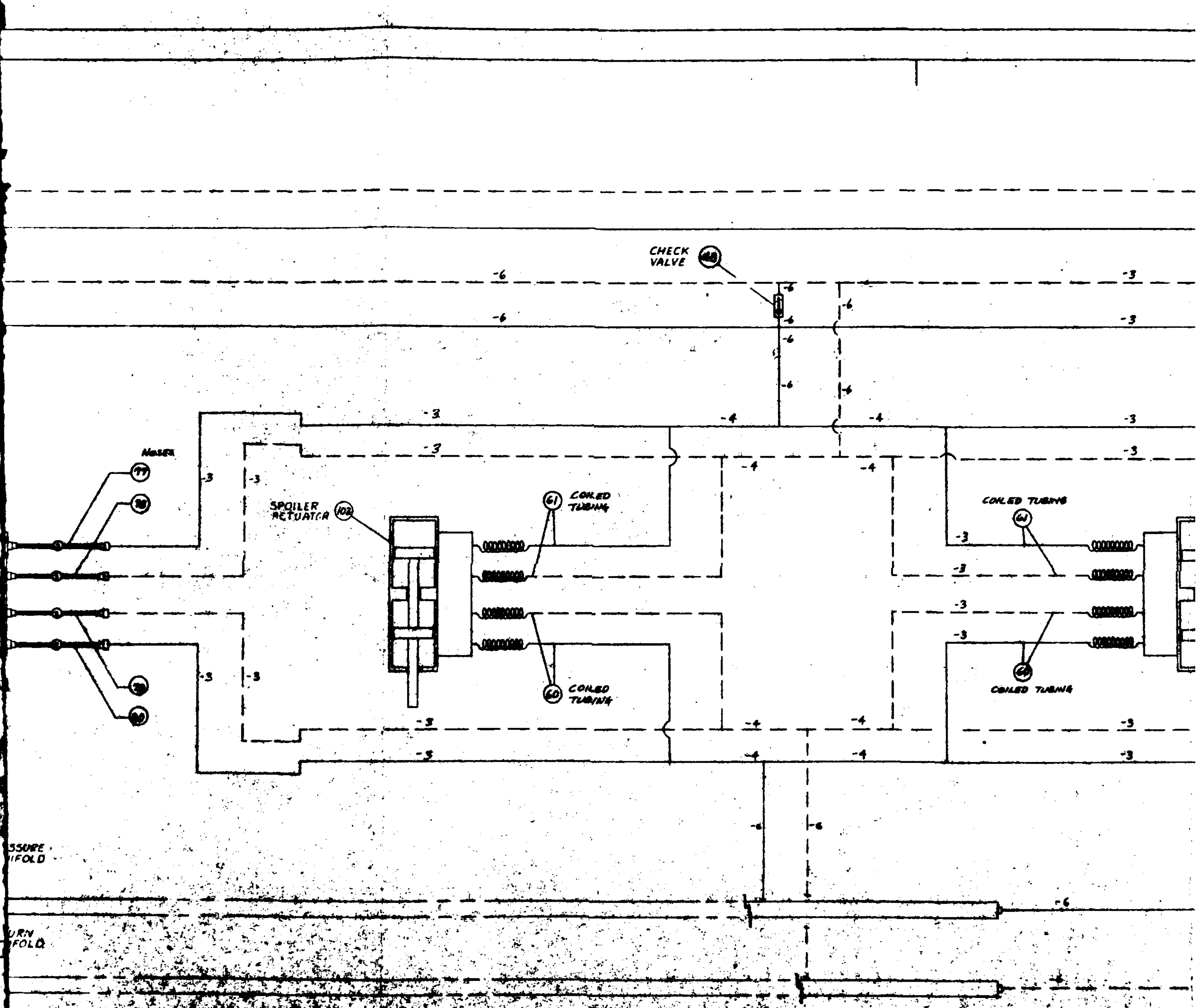
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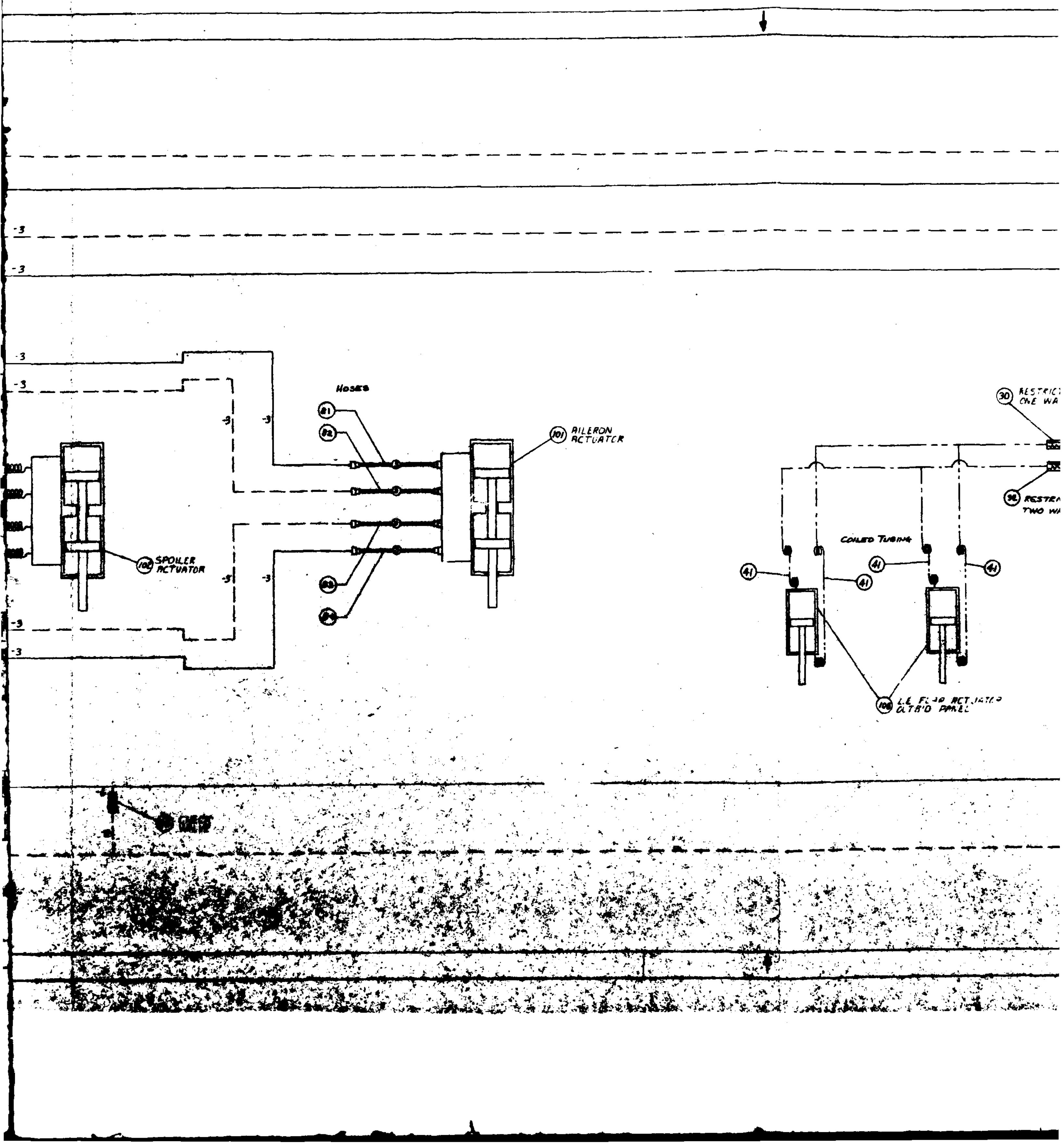
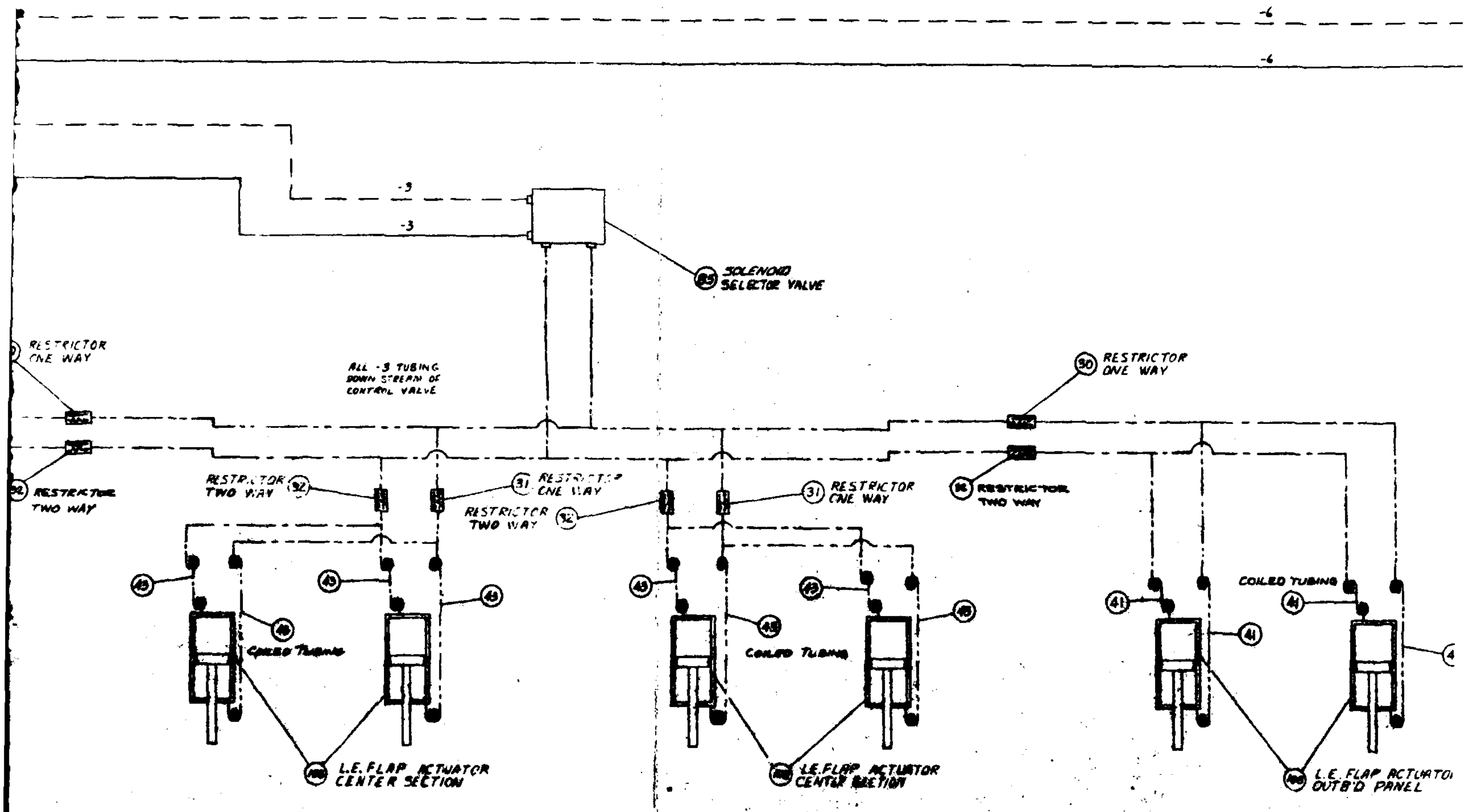
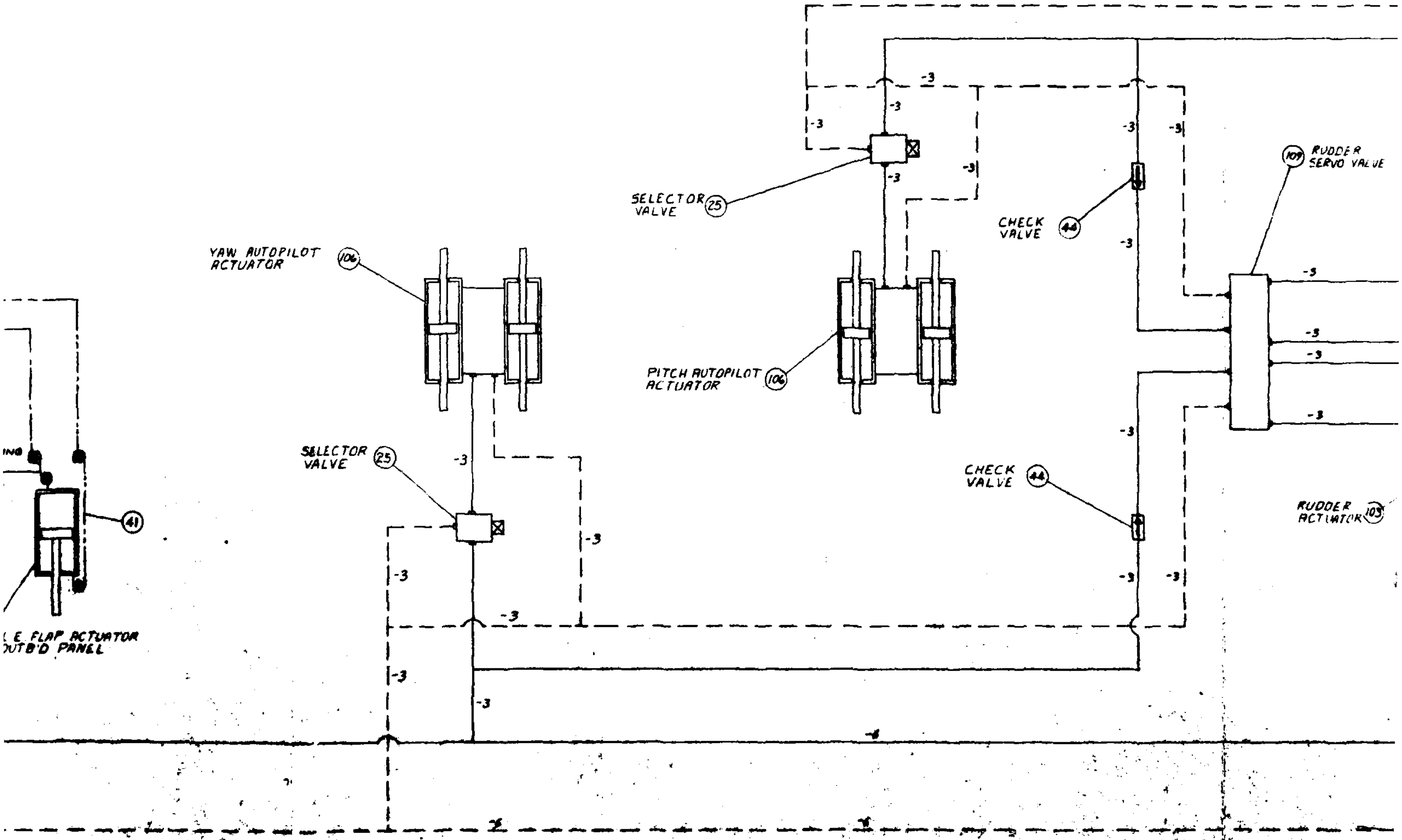


-3
-3
-3
-3
-3
-3
-3
-3
-3
-3
HOSES
81
82
101 AILERON ACTUATOR
102 SPOILER ACTUATOR
COILED TUBING
41
41
41
41
30
96

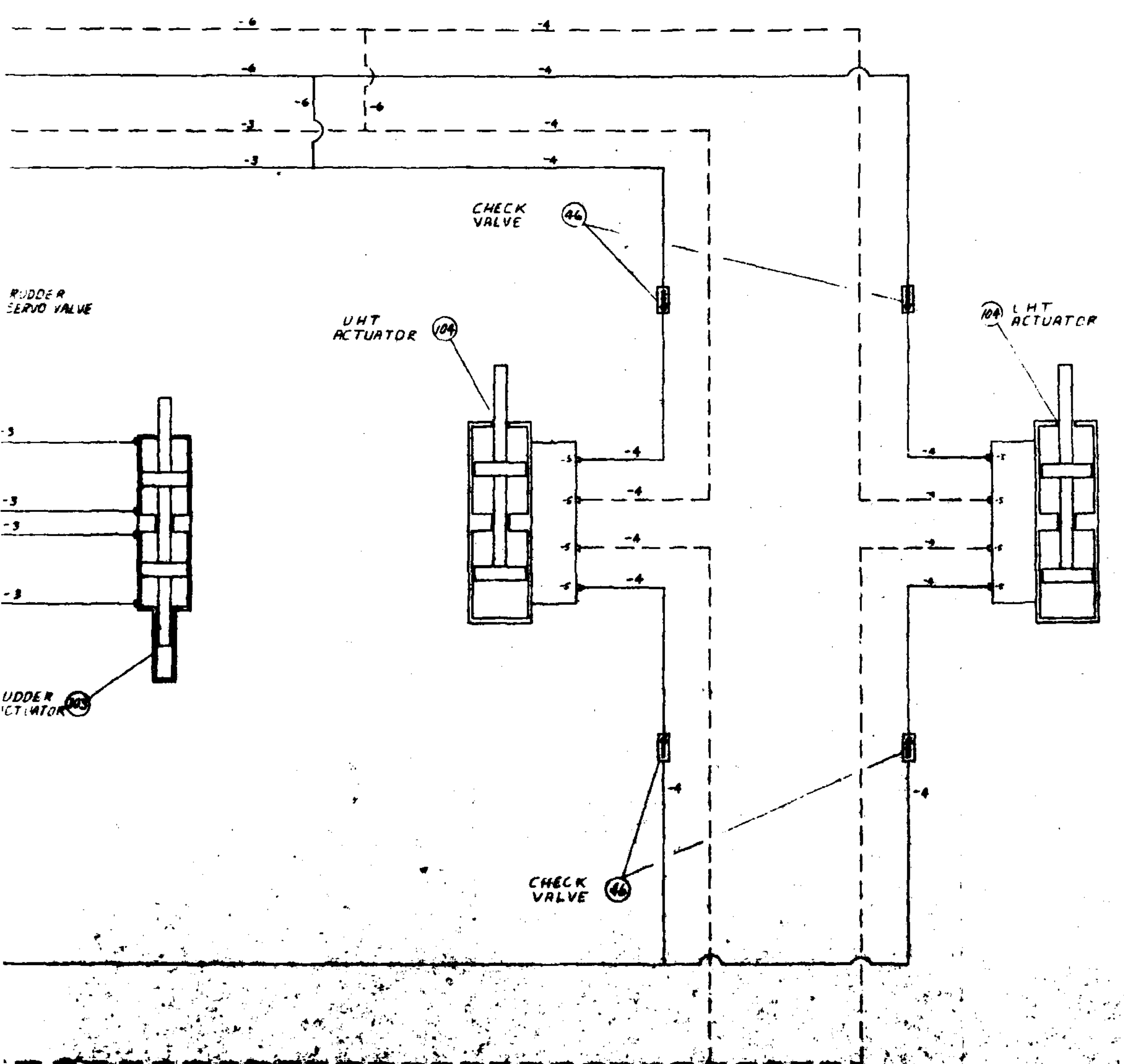


LEADING EDGE FLAP



7

YAW AUTOPILOT | PITCH AUTOPILOT | RUDDER



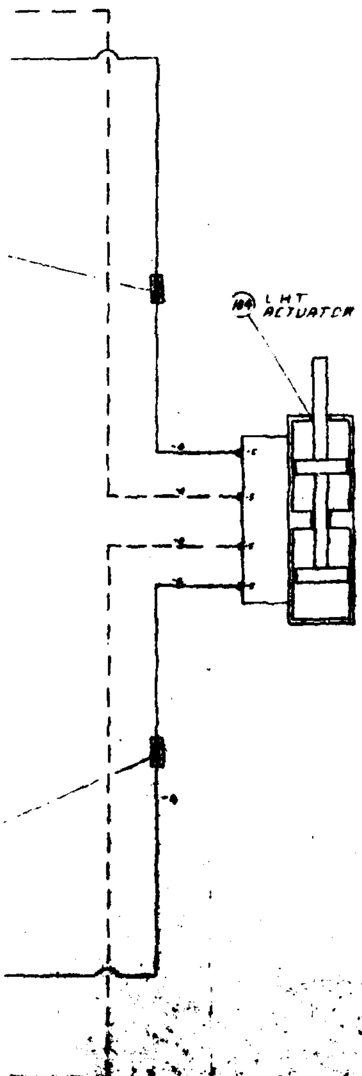
A
1. REPLACE… WITH CO…
2. REPLACE… WITH CO…
3. REPLACE… (ITEMS… TUBE AN…
4. DELETED… UNLOADI…
5. REPLACE… (ITEM 26… VALVE (…
6. REVISE…
7. UPDATE…
8. ADDED… FILTE…

B
1. ADDED… EXISTING… TO FACE…
2. REMOV… FROM SY… AILERON…
3. REMOV… (29) FROM… SOLENOID…
4. REMOV… RETURN…
5. REMOV… PRESSURE…
6. REMOV… SYSTEM…
7. ADDE…

NOTE: THE FO… INSTALLED IN TH… RH… RH… ROLL…

FIGURE 3

…HORIZONTAL TAIL



REVISIONS

ZONE	LTR	DESCRIPTION		DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NEW SHOP PRACTICE 5. PARTS MADE OK			
	A	1. REPLACED LEADING EDGE SWIVELS WITH COILED TUBE (ITEMS 41,42,43)	3		
		2. REPLACED WING/FUS. SWIVELS WITH COILED TUBE (ITEMS 38,39,40)	3		
		3. REPLACED LINE EXTENSION UNITS (ITEMS 57 THRU 63) WITH COILED TUBE AND HOSES (ITEMS 77 THRU [illegible])	3		
		4. DELETED SPEED BRAKE MANUAL UNLOADING VALVE (ITEM 22)	3		
		5. REPLACED MANUALLY OPER. VALVE (ITEM 26) WITH SOLENOID OPER. VALVE (ITEM 85) ADDED ITEM 76			
		6. REVISED CHECK VALVE CALLOUTS	3		
		7. UPDATED SHT 2 TABLES	3		
		8. ADDED FCI PUMP CASE DRAIN FILTER	-	R. HOLLAND 12 DEC. 1980	
	B	1. ADDED MISSING AND REVISED EXISTING ITEM NUMBER CALLOUTS TO FACE OF DRAWING.	3		
		2. REMOVED CHECK VALVE (44) FROM SYSTEM RETURN LINE IN AILERON AND SPOILER SECTION	3		
		3. REMOVED ONE WAY RESTRICTOR (29) FROM LEADING EDGE FLAP SOLENOID SELECTOR VALVE (85)	3		
		4. REMOVED (43) FROM SYSTEM RETURN. (2 PLCS)	3		
		5. REMOVED (37) FROM SYSTEM PRESSURE. (8 PLCS)	3		
		6. REMOVED (32), ADDED (36) TO SYSTEM PRESSURE. (2 PLCS)	3		
		7. ADDED NOTE.	3	R. WISE 8 OCT 1985	

NOTE: THE FOLLOWING ACTUATORS WERE NOT INSTALLED IN THE LHS SIMULATOR:
R.H. AILERON, RH SPOILER,
RH. LE FLAPS (4),
ROLL AUTOPILOT, PITCH AUTOPILOT

FIGURE 3

9

SCHEMATIC DIAGRAM FCI? [illegible] HYDRAULIC SYSTEM

...RONTAL TAIL

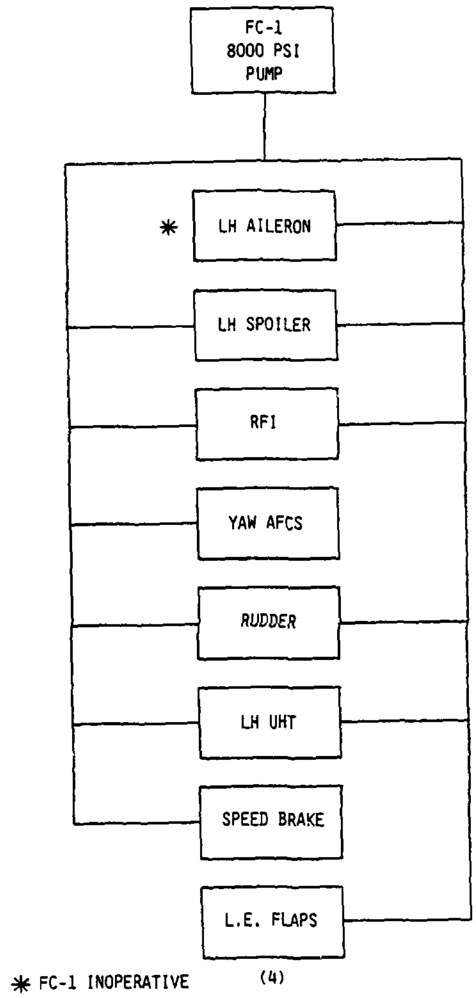


FIGURE 4. Initial test system (1st 300 hrs.)

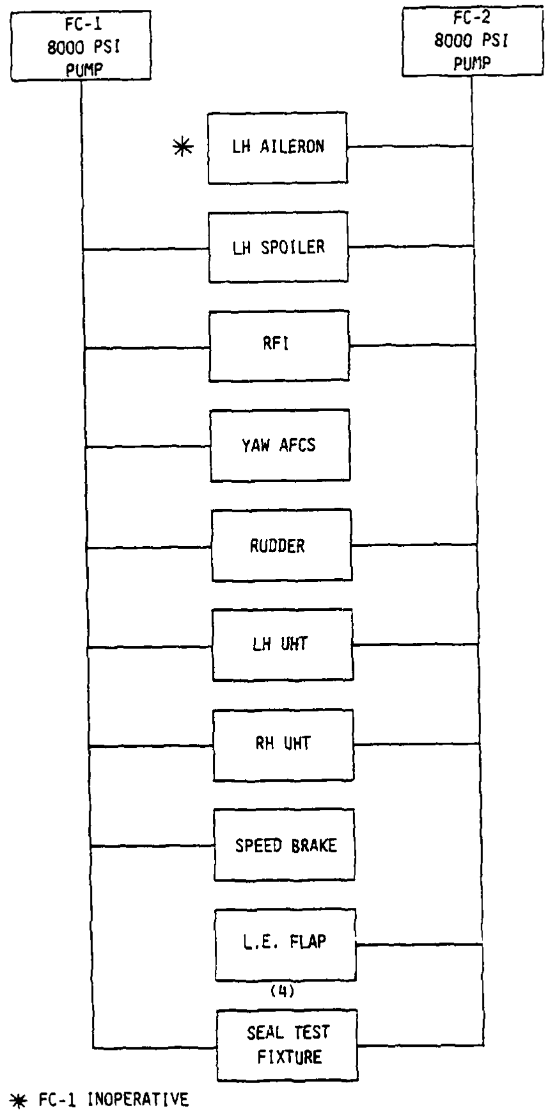


FIGURE 5. Final test system (2nd 300 hrs.)

3.0 SIMULATOR DESIGN

3.1 SIMULATOR ASSEMBLY

The LHS simulator is a steel structure with aircraft hydraulic component installations designed to represent a full scale A-7E 8000 psi flight control system, Figures 6, 7, and 8. Fuselage structure is primarily 3 inch square steel tubing; wing structure is principally 8 inch steel channel. Modular design was employed to facilitate fabrication and permit separate testing of individual actuators. Two types of modules were used: power modules and load modules.

Power Modules	Designer/Fabricator
FC-1 System	NAAO-Columbus
FC-2 System	NAAO-Columbus
Load Modules	
Aileron, LH	Vought
Spoiler, LH	Vought
UHT, LH & RH	Vought, Blacklick Machine
Rudder	NAAO-Columbus
Speed Brake	Vought
Leading Edge Flap, LH Inboard & LH Outboard	Vought

Each power module contains a pump, reservoir, filters, and valving to supply/receive hydraulic fluid to/from the flight control actuators. Each actuator is mounted in a load module that duplicates the kinematics of an A-7E installation. Load/stroke conditions imposed on each actuator are based on specific, individual requirements. Load cylinders in the modules are powered by a 2300 psi hydraulic system.

Mechanical control linkages -- push-rods, bellcranks, and load-limiting bungees -- drive LHS actuator input levers. Linkages from SARDIP A-7 aircraft were used wherever possible to reduce costs.

The simulator can be controlled manually or automatically. Manual control is by "pilot stick" or through manipulating dials and switches on a console panel. Automatic control is provided by a mechanical programmer. Both the manual and automatic controls utilize fiber optics to transmit signals to the simulator. The fiber optics system controls the roll, pitch, and yaw AFCS actuators by microcomputer multiplexing/processing of the command and feedback signals of each axis.

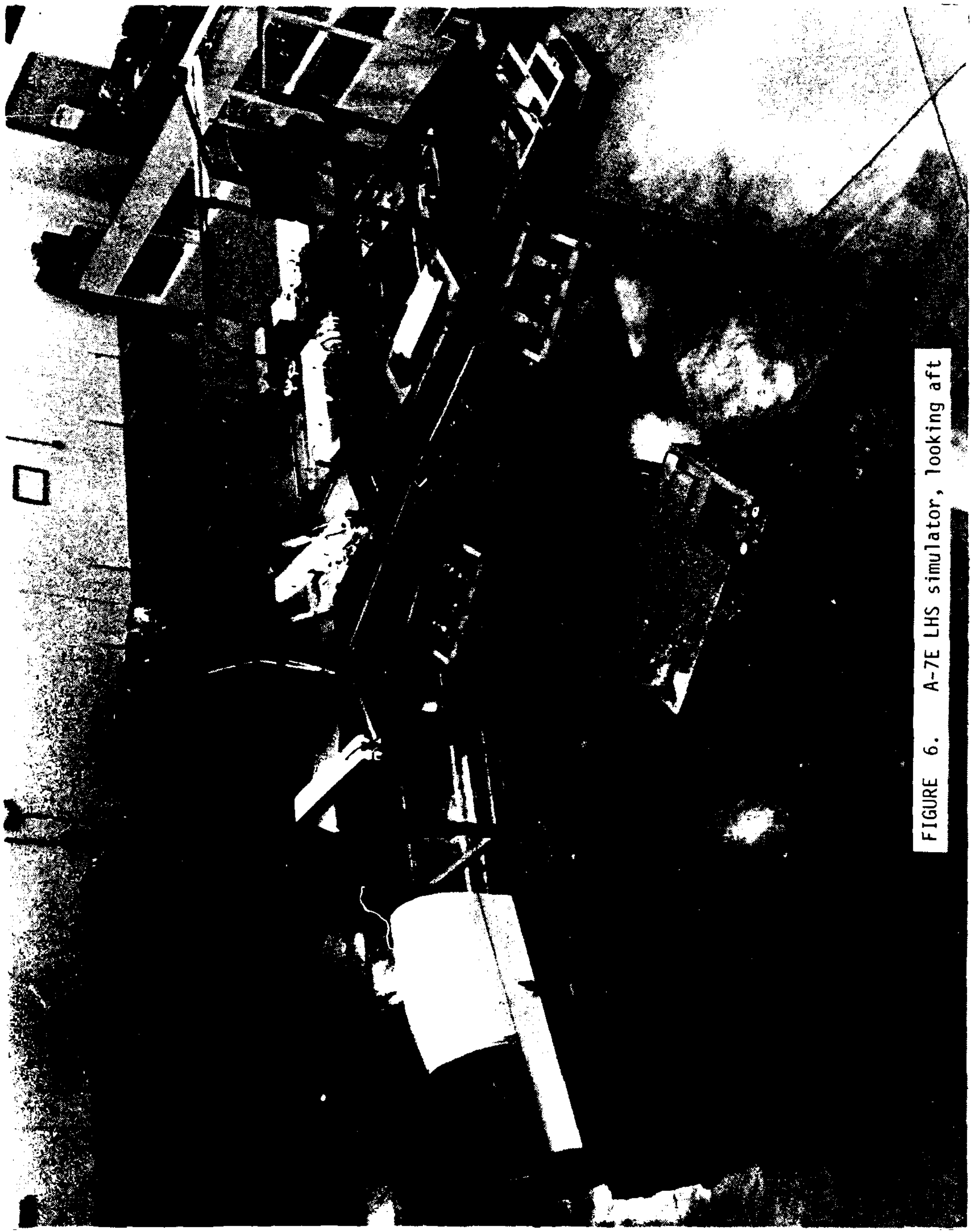


FIGURE 6. A-7E LHS simulator, looking aft

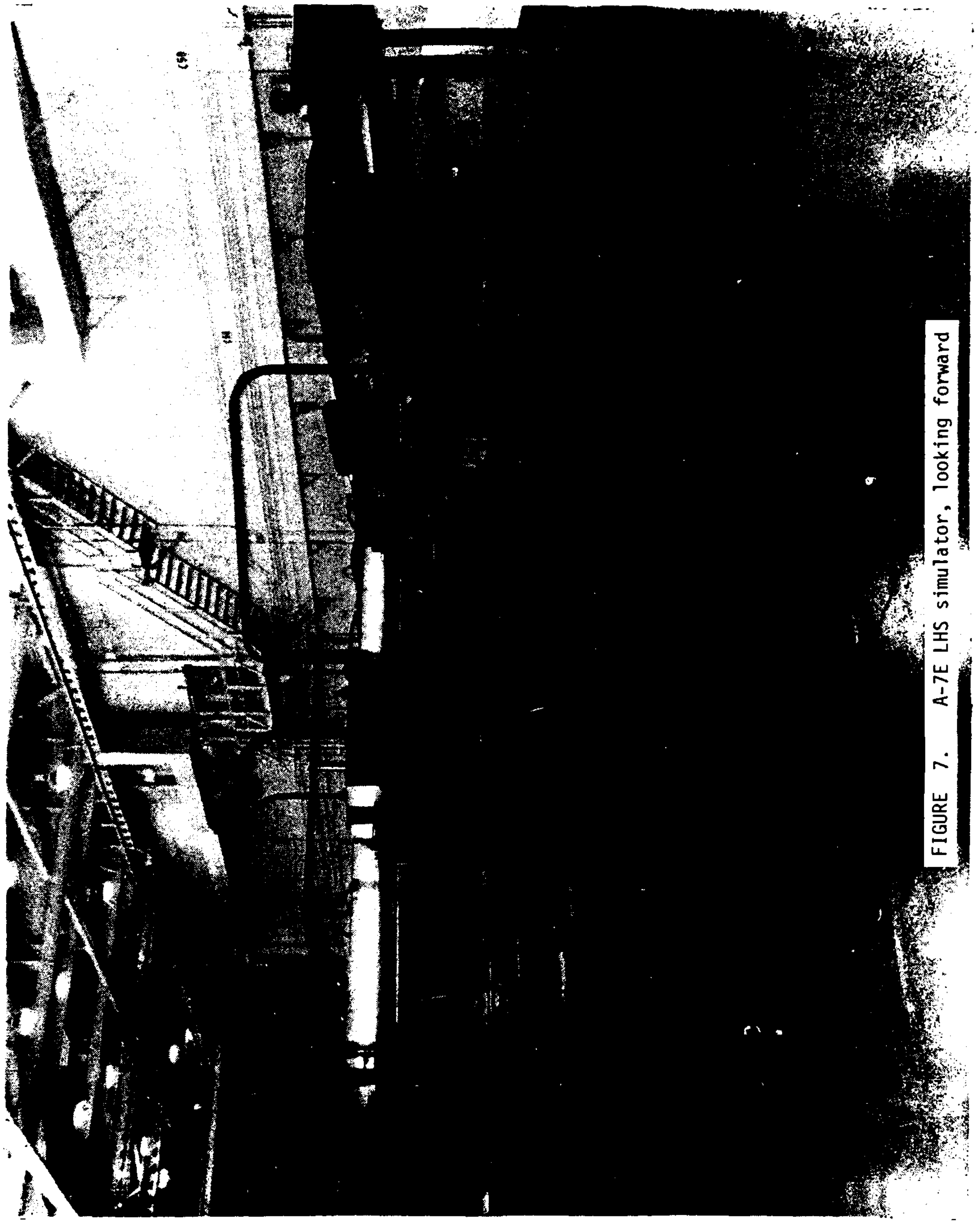


FIGURE 7. A-7E LHS simulator, looking forward

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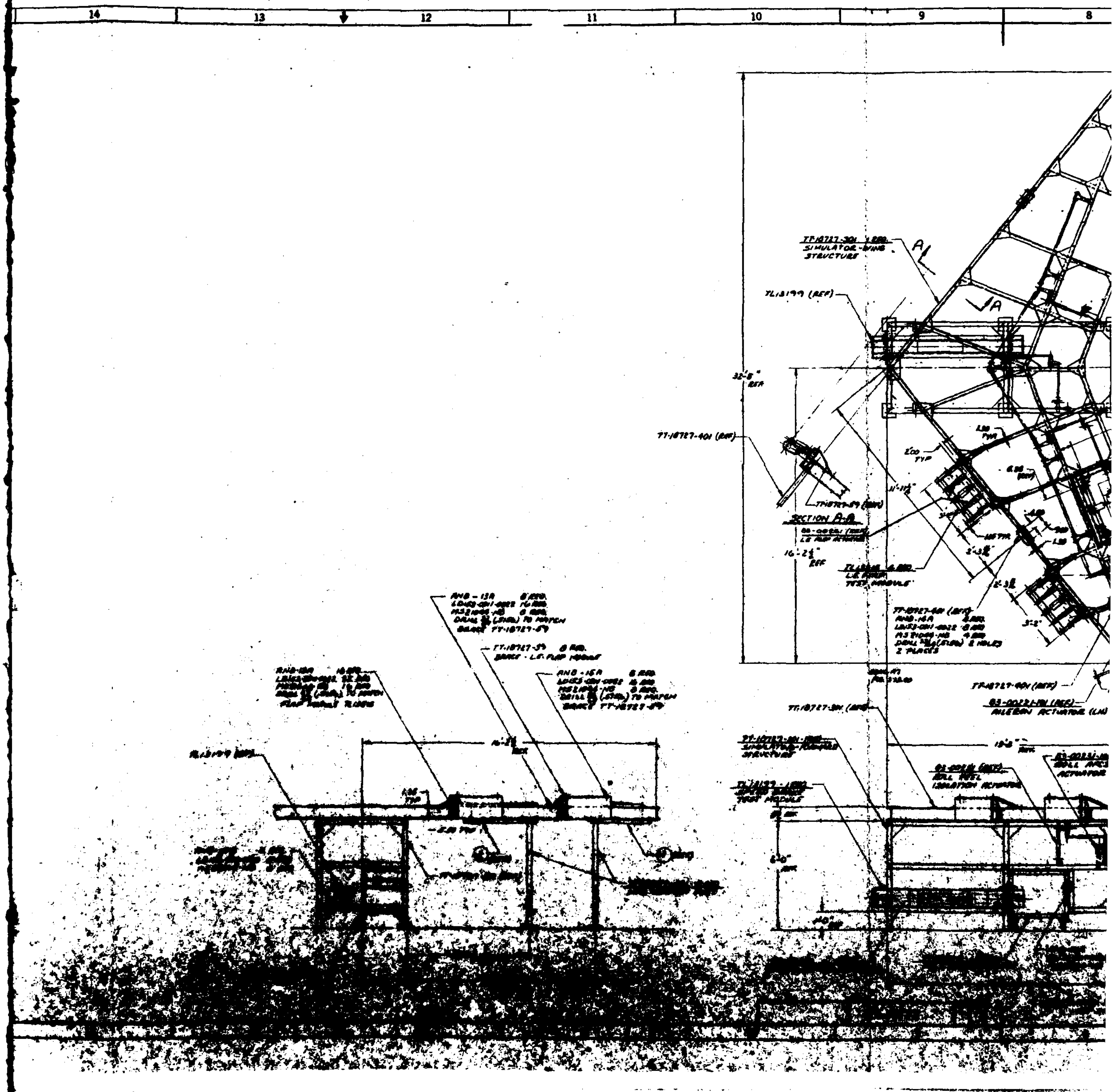
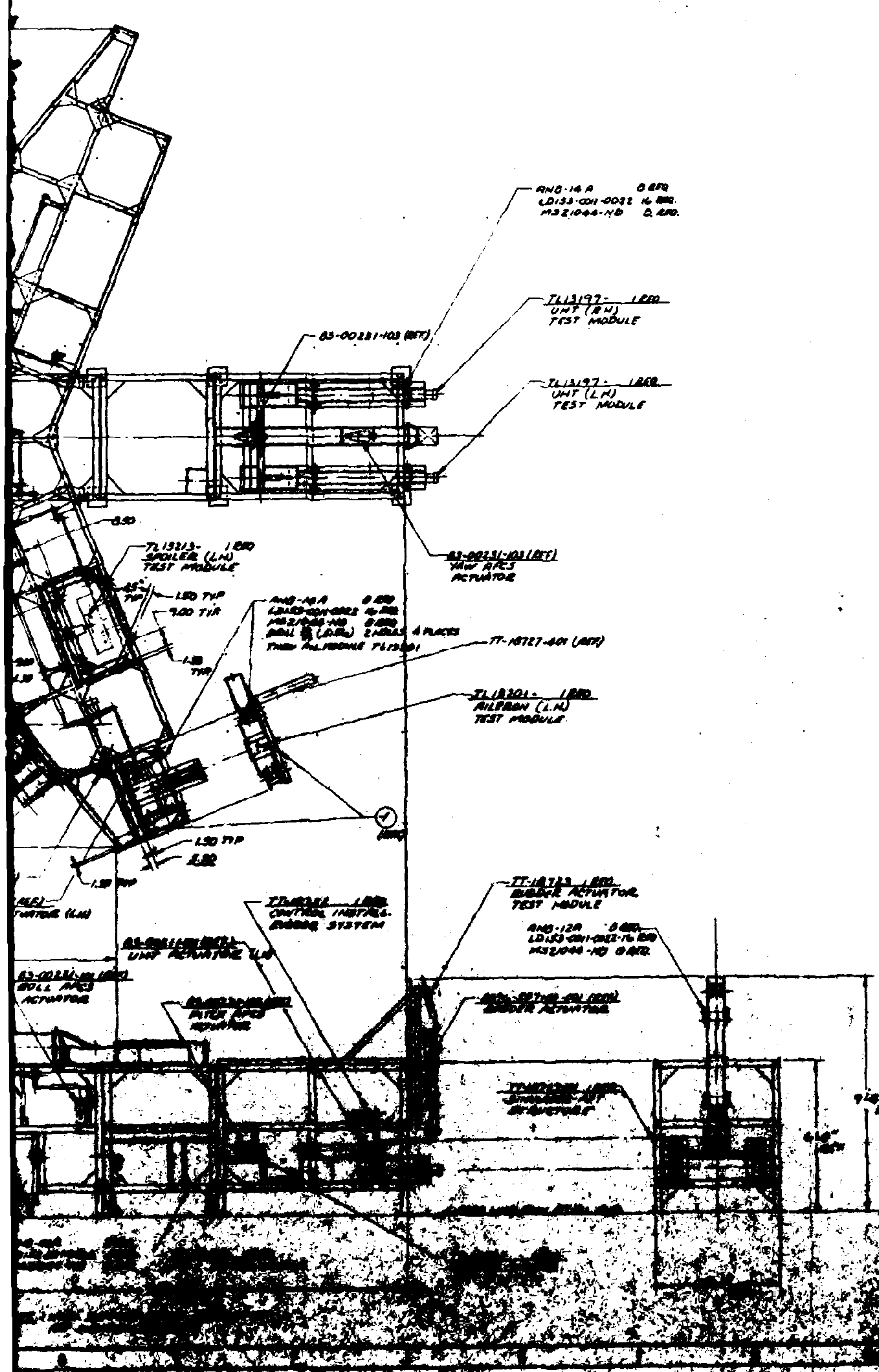


14
13
12
11
10
9
8
SECTION A-A
TT-18727-401 (REF)
TL13199 (REF)
TT-18727-301 1 REQ.
SIMULATOR-WING
STRUCTURE
TT-18727-59 8 REQ.
BRACE - L.E. FLAP MODULE



70	MS21044-N6	NUT
156	LD153-0011-0022	WASHER
2	AN6-40A	BOLT
8	AN6-15A	BOLT
20	AN6-14A	BOLT
40	AN6-13A	BOLT
8	AN6-12A	BOLT
4	-3	AFT. SUPP. SPOILER MOD.
2	-2	SUPPORT SPOILER MOD.
2	-1	SUPPORT - AIL. MODULE
2	TL13214	L.E. FLAP MODULE
1	TL13213-	L.H. SPOILER MODULE
1	TL13201-	L.H. AILERON MODULE
1	TL13199	SPEED BRAKE MODULE
1	TL13197-	R.H. UHT MODULE
1	TL13197-	L.H. UHT MODULE
8	TT-18727-89	BRACE FLAP MOD.
1	TT-18732	RUD. CONTROL MODULE
1	TT-18731	UHT CONTROL MECH.
1	TT-18730	AILERON & SPOILER CONTROL MECHANISM
4	TT-18727-401	SIMULATOR-WING FWD
1	TT-18727-301	SIMULATOR-WING SECT
1	TT-18727-201	SIMULATOR - FWD. SECT
1	TT-18727-101	SIMULATOR - AFT SEC.
1	TT-18726	FC-2 POWER MODULE
1	TT-18724	FC-1 POWER MODULE
1	TT-18723	RUDDER ACT. MODULE
	PART NO.	NOMENCLATURE

FIGURE 8

78	MS21044-N3	NUT		
156	LD153-0011-0022	WASHER		
2	AN6-40A	BOLT		
8	AN6-15A	BOLT		
20	AN6-14A	BOLT		
40	AN6-13A	BOLT		
8	AN6-12A	BOLT		
4	-5	AFT. SUPP. SPOILER MODULE	2½ x 2½ x ¼ ANGLE x 1'4⅜	LOW CARBON STEEL
2	-2	SUPPORT-SPOILER MOD.	2½ x 2½ x ¼ ANGLE x 4'4⅜	LOW CARBON STEEL
2	-1	SUPPORT-AIL. MODULE	2½ x 2½ x ¼ ANGLE x 3'6⅜	LOW CARBON STEEL
2	TL13214	L.E. FLAP MODULE		
1	TL13213-	L.H. SPOILER MODULE		
1	TL13201-	L.H. AILERON MODULE		
2	TL13199	SPEED BRAKE MODULE		
1	TL13197-	R.H. UNIT MODULE		
1	TL13197-	L.H. UNIT MODULE		
8	TT-18727-89	BRACE-FLAP MOD.		
1	TT-18732	R.B. CONTROL INSTALL.		
1	TT-18731	UNIT CONTROL INSTALL.		
1	TT-18730	AILERON & SPOILER CONTROL MECHANISM		
4	TT-18727-401	SIMULATOR-WING FWD		
1	TT-18727-301	SIMULATOR-WING SECT.		
1	TT-18727-201	SIMULATOR-FWD. SECT.		
1	TT-18727-101	SIMULATOR-AFT SECT.		
1	TT-18726	FC-2 FRAME MODULE		
1	TT-18724	FC-1 FRAME MODULE		
1	TT-18723	RUDDER ACT. MODULE		
REQ.	PART NO.	NOMENCLATURE	SIZE	SPECIFICATION

PARTS LIST

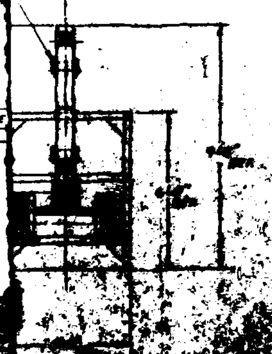


FIGURE 8

UNLESS OTHERWISE NOTED

3.2 MODULES

3.2.1 Power Modules

Photographs of FC-1 and FC-2 power modules are presented as Figures 9 and 10. Hydraulic components used in the modules are listed below, and described briefly in Tables 1 and 2.

	Quantity			
	FC-1 Module		FC-2 Module	
	8000 psi Component	Return System Component	8000 psi Component	Return System Component
Pump	1		1	
Quick Disconnect	2	3	2	3
Hose	1	2	1	2
Reservoir	1		1	
Check Valve	2	4	3	6
Filter	1	2	1	2
Relief Valve	1	1	1	1
Solenoid Valve, 2-Way			1	
Solenoid Valve, 4-Way	1			
Accumulator			1	
Pressure Transmitter	1		1	
Pressure Snubber	1		1	
Restrictor	1			
Pressure Gage			1	

Both modules contained provisions for mounting components in locations representative of an A-7E installation. Transmission line lengths, routing, fittings, and clamps were as close as practical to those anticipated in the aircraft. Some minor variations in plumbing were necessary to accommodate temperature, pressure, and flow instrumentation. Both pumps were placed at a low elevation to simulate engine mounting and assure realistic suction line pressures. A 100 horsepower varidrive with two mounting pads was used to power the pumps. An oil-to-water heat exchanger was installed in the case drain line of each pump to provide a means for fluid temperature control, if required.

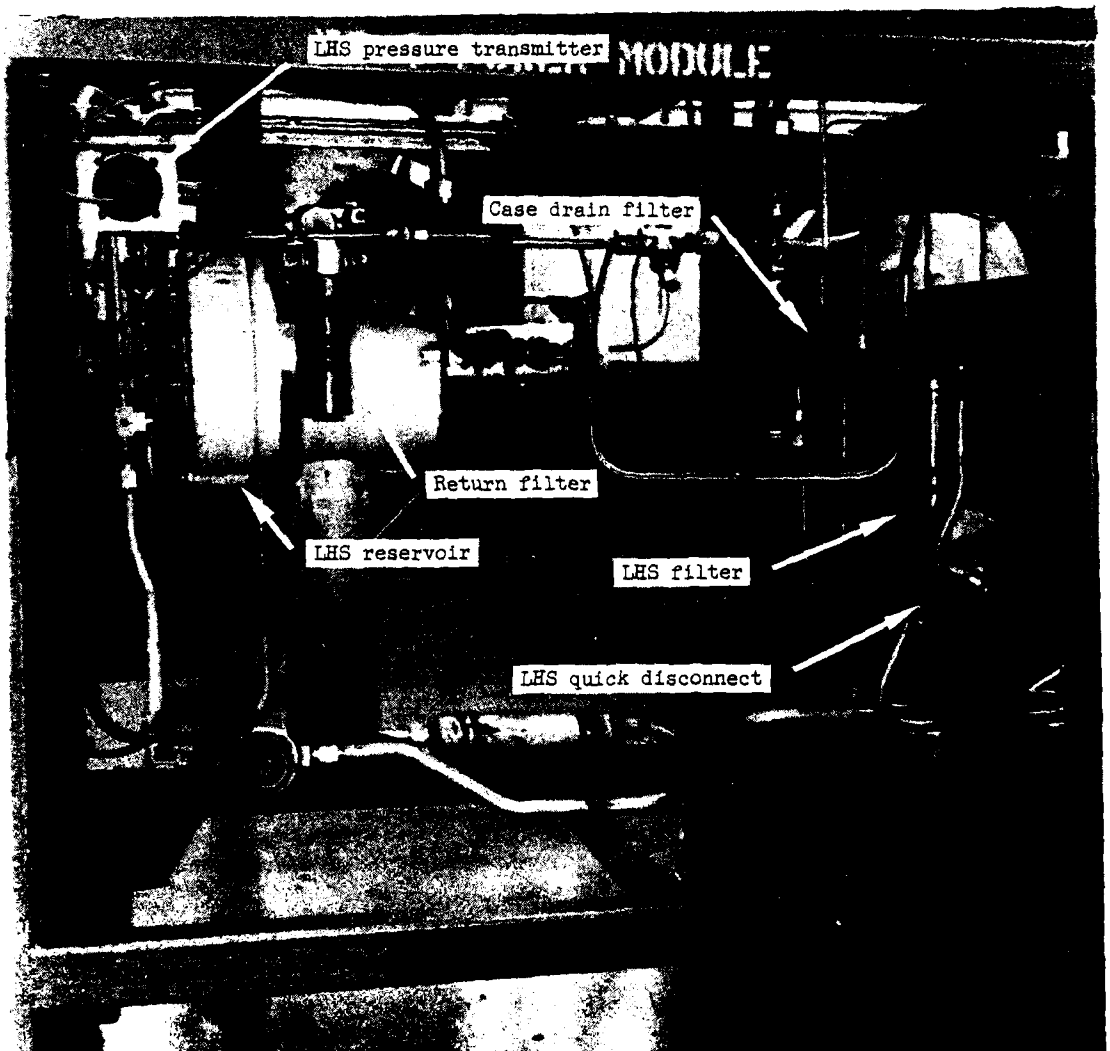


FIGURE 9. FC-1 power module

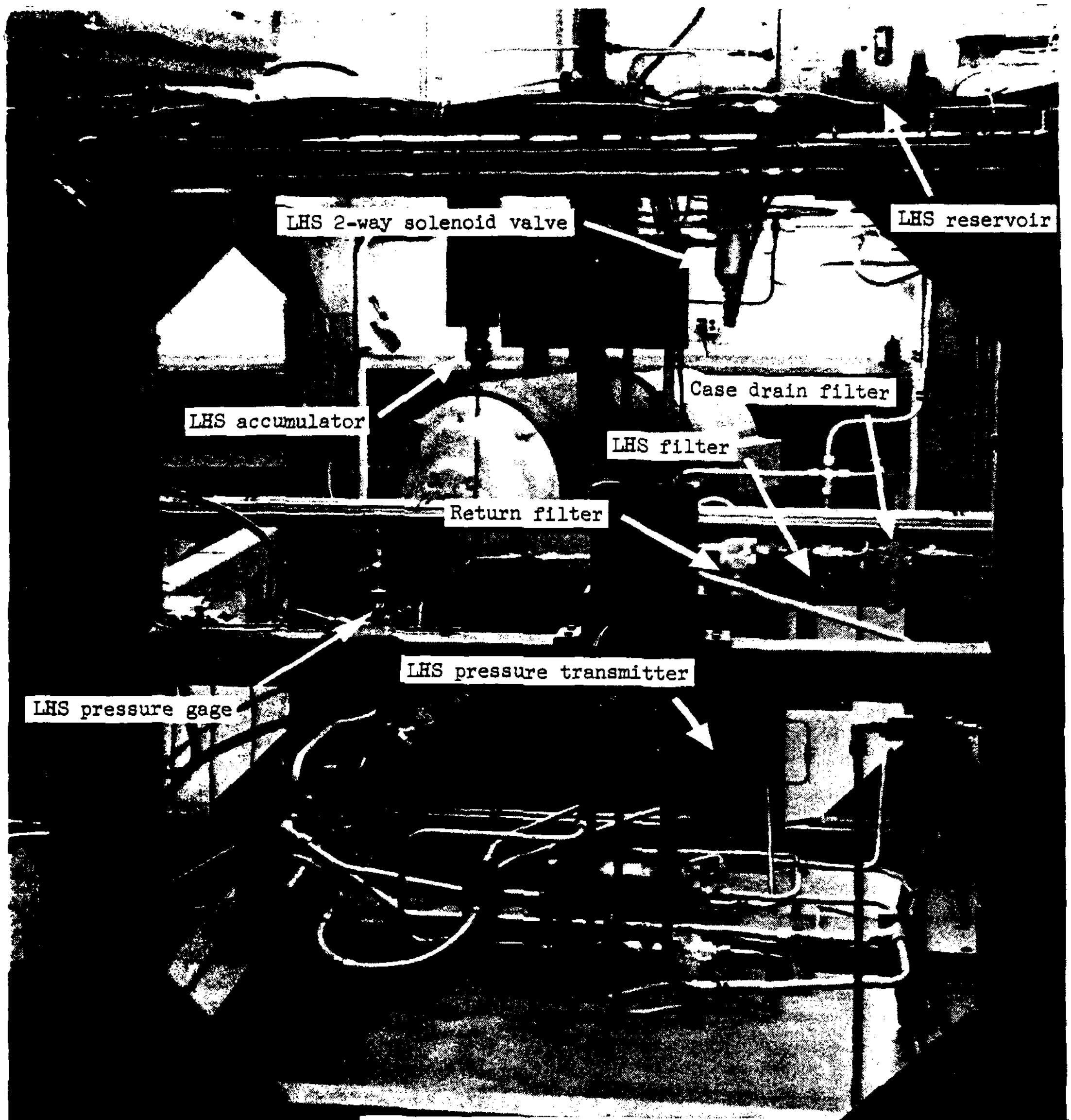


FIGURE 10. FC-2 power module

3.2.2 Load Modules

3.2.2.1 Aileron. The aileron actuator is mounted in a linkage system identical to the aircraft installation, Figure 11. Piston rod travel and actuator body motion combine to deflect a load cylinder producing the load/stroke curve shown on Figure 12. Four hoses are used to transmit hydraulic power to the actuator. The actuator input lever is operated by a push-rod in the simulator roll axis control system. Mechanical input is by the RFI and roll AFCS actuators. The AFCS actuator was obtained from a SARDIP A-7 and was powered by the 2300 psi load system.

3.2.2.2 Spoiler/Deflector. The spoiler/deflector actuator is installed in a toggle linkage arrangement utilizing A-7E parts, Figure 13. Piston rod travel and actuator body motion combine to oppose a load cylinder resulting in load/stroke characteristics as shown on Figure 14. Four coil tubes are used to transmit hydraulic power to the actuator. The actuator input lever is operated by a push-rod in the simulator roll axis control system. A motion limiting bungee prevents the LH actuator from responding to pilot "stick right" inputs.

3.2.2.3 Unit Horizontal Tail (UHT). The LH and RH UHT actuators are each installed in a module that provides mounting and kinematics identical to the aircraft installation, Figure 15. Control of the actuator input levers is through an A-7 linkage system that includes structural feedback. Actuator loading is developed when an industrial-type cylinder is forced away from a neutral position, Figure 16. Hydraulic power is supplied through tubing that flexes as the actuators stroke. The LH and RH actuator input linkages are operated jointly by a torque tube driven by the AFCS pitch actuator. The pitch actuator was obtained from a SARDIP A-7 and was powered by the 2300 psi load system.

3.2.2.4 Rudder. The rudder module, Figure 17, contains several A-7 aircraft components: control valve housing, valve input linkage, structural feedback linkage, and structural load forging. Rudder actuator mounting and swivelling is identical to the aircraft installation. Load/stroke characteristics are shown on Figure 18. Hydraulic power is supplied to the actuator through tubing that flexes as the piston rod moves. Rudder input is controlled by an 8000 psi AFCS pitch actuator through a load-limiting bungee.

3.2.2.5 RFI and AFCS Actuators

RFI. The roll-feel isolation (RFI) actuator is a floating power link in the airplane roll control push rod system. This unit is used to drive the aileron actuator servo valves, one spoiler valve, and one bungee spring. Since the simulator control system provided normal loading on the RFI actuator, a load module was not required, Figure 19.

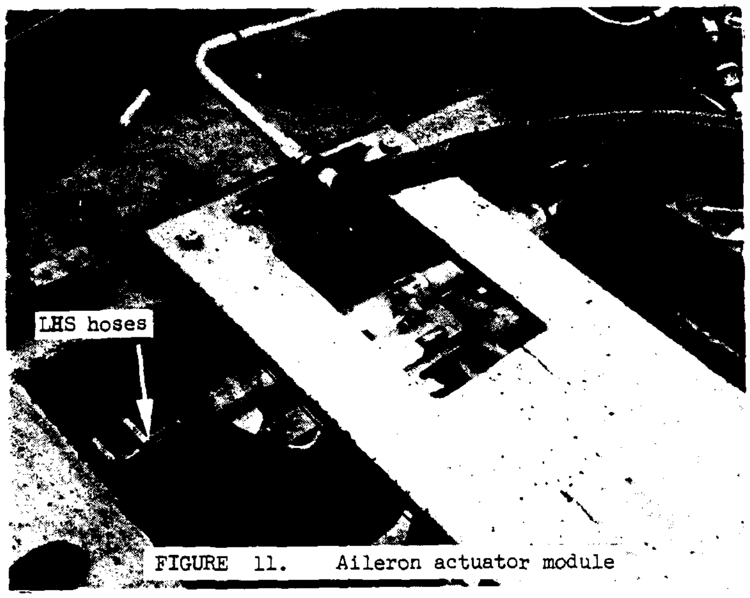


FIGURE 11. Aileron actuator module

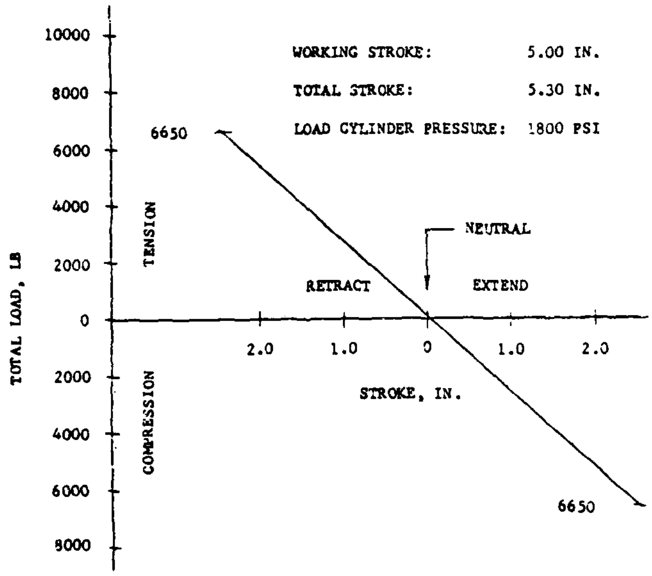


FIGURE 12. Aileron actuator load/stroke curve

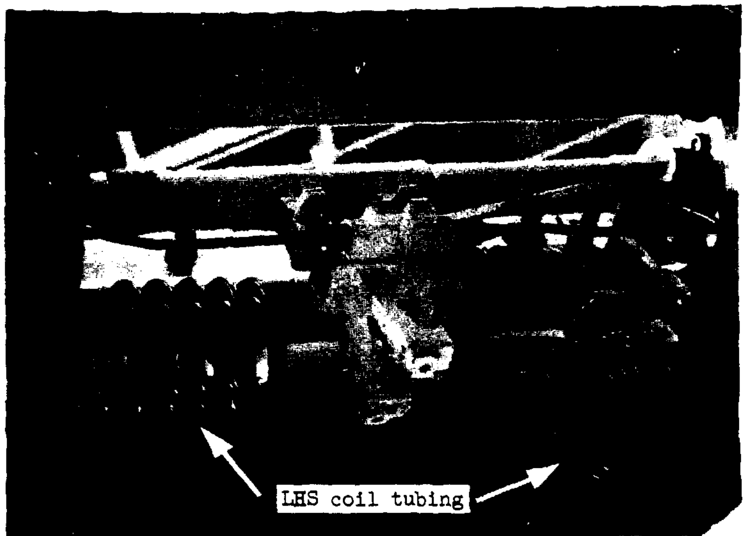


FIGURE 13. Spoiler/deflector actuator module

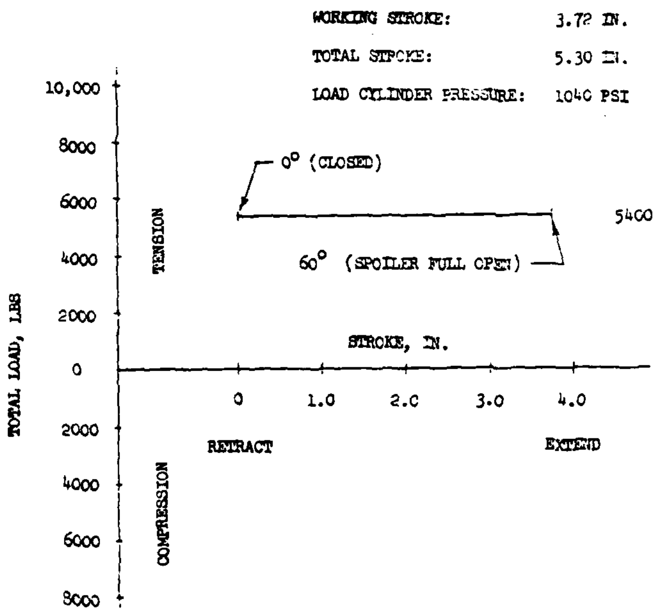


FIGURE 14. Spoiler/deflector actuator load/stroke curve

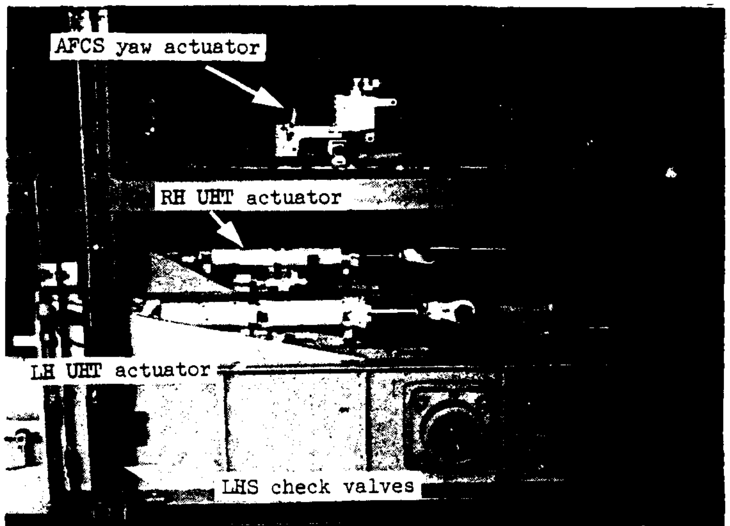


FIGURE 15. LH unit horizontal tail module

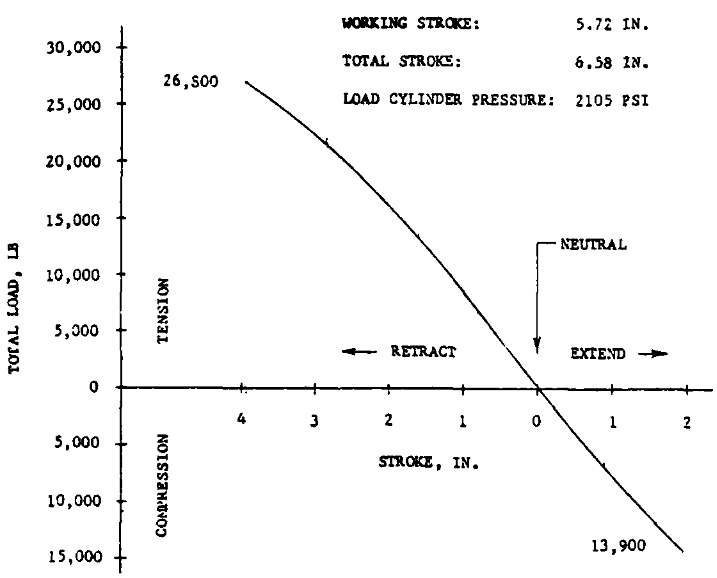


FIGURE 16. UHT load/stroke curve

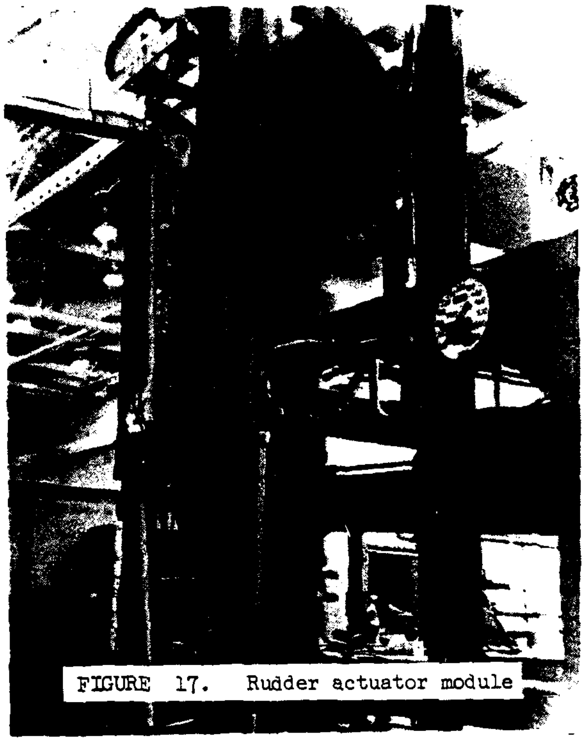


FIGURE 17. Rudder actuator module

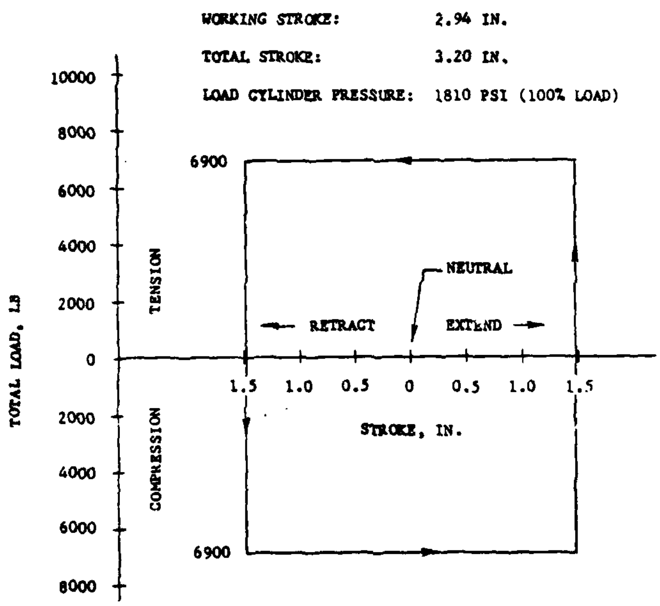


FIGURE 18. Rudder actuator load/stroke curve

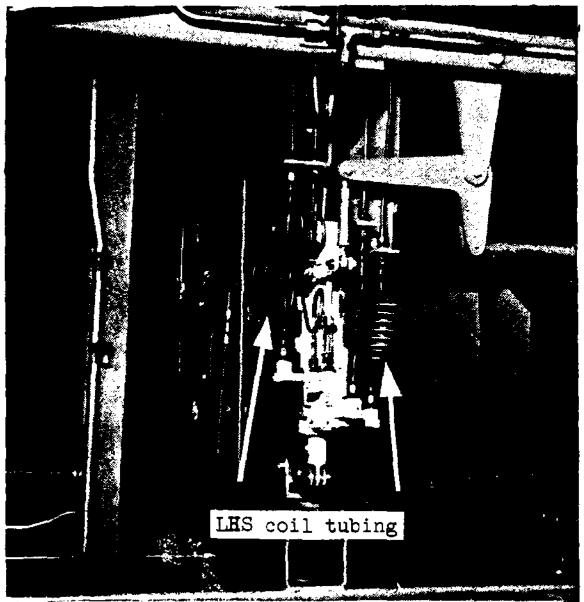


FIGURE 19. Roll feel isolation actuator

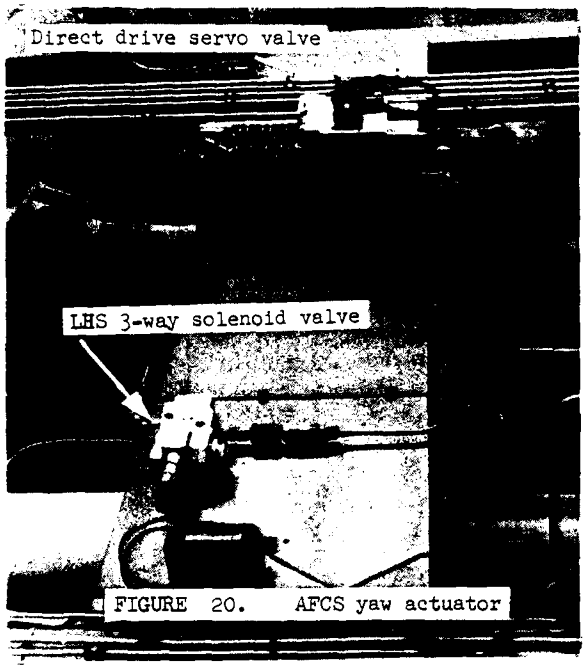


FIGURE 20. AFCS yaw actuator

AFCS. The A-7 has three automatic flight control system (AFCS) actuators, one each for the roll, pitch, and yaw axes of the airplane. In the LHS simulator, the roll and pitch AFCS actuators operate at 2300 psi; the yaw actuator operates at 8000 psi and has a direct drive servo valve, Figure 20. The actuators are controlled electrically and have hydro-mechanical provisions to center and lock the pistons when the actuator is "off". Since the AFCS actuators drive only hydraulic control valves, load modules were not required.

3.2.2.6 Speed Brake. The motion of the A-7 speed brake actuator requires a minimum vertical height of 75 inches. Space constraints in the LHS simulator prohibited duplicating the aircraft geometry and motion of the speed brake actuator. The speed brake load module was therefore designed to provide realistic loading in a fixture suitable for use in the simulator, Figure 21.

The speed brake actuator is loaded by an industrial cylinder, and controlled by a 4-way solenoid valve located on the FC-1 power module. The load/stroke curve is shown on Figure 22. A restrictor in the 4-way valve limits speed brake piston velocity to maintain system pressure.

3.2.2.7 Leading Edge Flap. Two identical flap load modules are mounted on the LH wing leading edge, Figure 23. Each module contains two LE flap actuators and one load cylinder. Kinematics are identical to an aircraft installation. Actuator location and mounting were modified to simplify module design and reduce costs. Coil tubes are used to transmit hydraulic power to the flap actuators. A 4-way solenoid valve ports fluid to all four actuators simultaneously. Both 1-way and 2-way restrictors are used to control actuator piston rates. Module load/stroke characteristics are shown on Figure 24.

3.2.2.8 Seal Test Fixtures. Seal test fixtures were mounted in the right hand wing at a location originally intended for the aileron load module, Figure 25. Four piston rod and two piston head seals were evaluated. Flow needed to operate the cylinders approximated aileron actuator flow and thus helped provide realistic pump loading.

The fixtures were originally built for endurance tests reported in References 7 and 10. The units were refurbished and modified for the LHS simulator as follows:

- The piston rods were re-chrome plated and ground
- One piston head containing a standard seal groove was fabricated
- Four seal retainers housing 2-stage unvented rod seals were fabricated

FIGURE 21. Speed brake actuator module

WORKING STROKE: 19.94 IN.

TOTAL STROKE: 19.94 IN.

LOAD CYLINDER PRESSURE: 2040 PSI (100% LOAD)

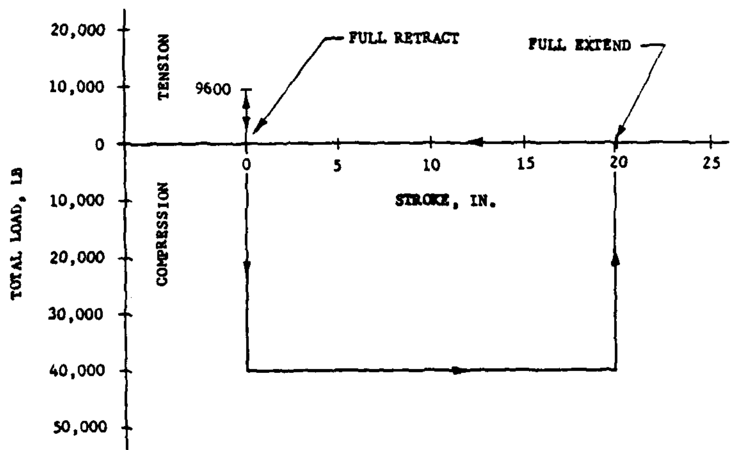


FIGURE 22. Speed brake actuator load/stroke curve

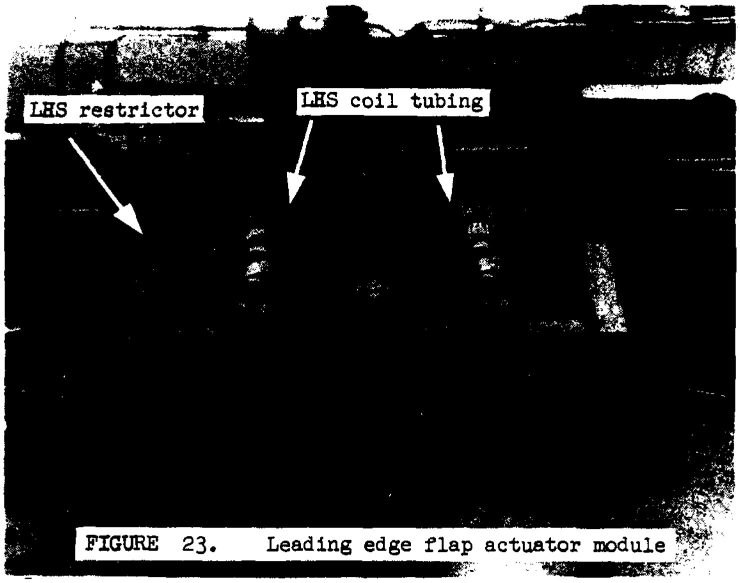


FIGURE 23. Leading edge flap actuator module

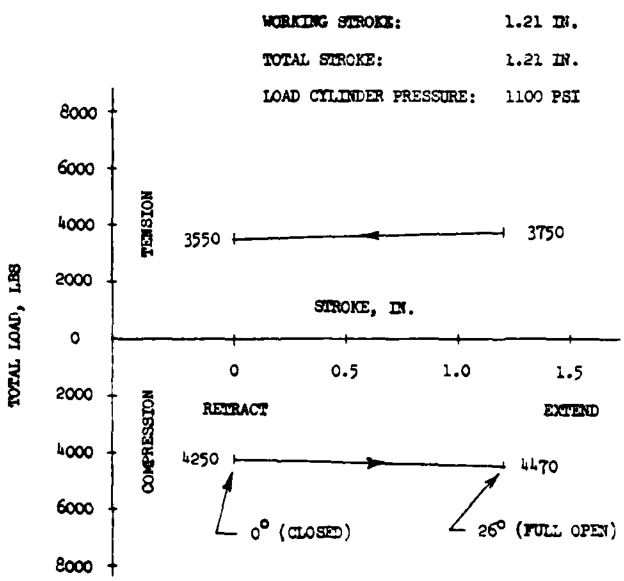


FIGURE 24. L.E. flap actuator load/stroke curve

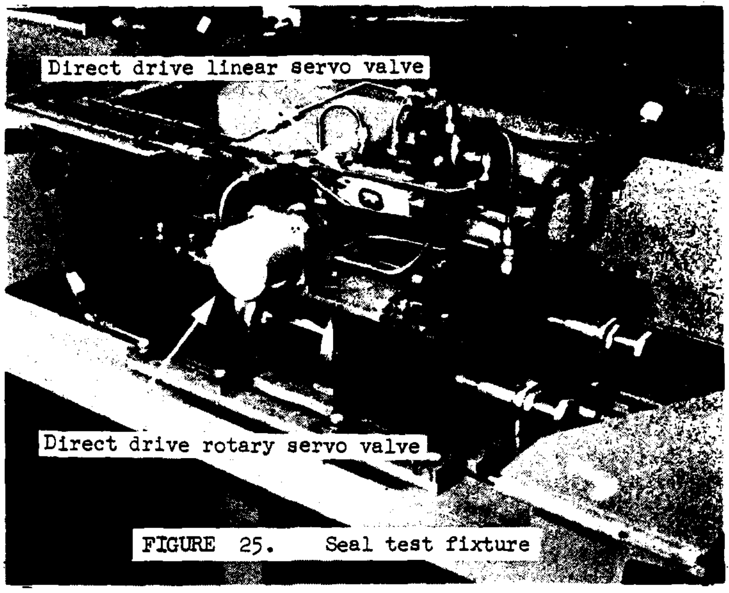


FIGURE 25. Seal test fixture

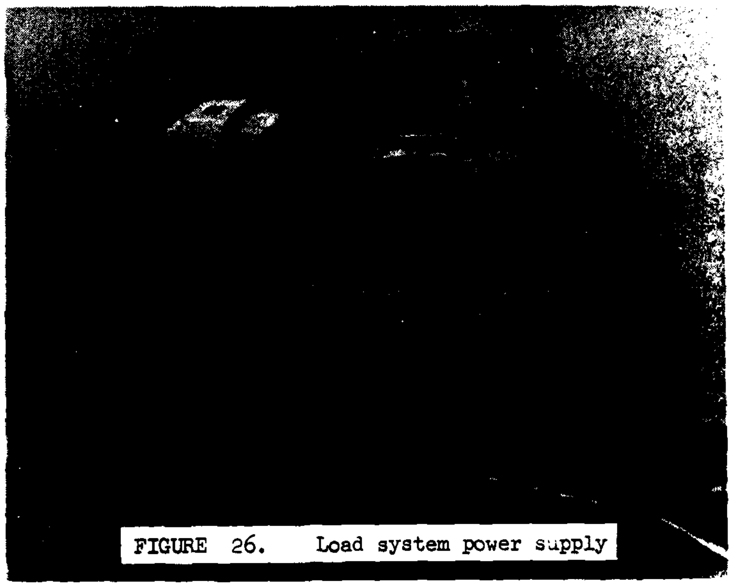


FIGURE 26. Load system power supply

Test seal manufacturers were:

Cylinder	Simulator System	Test Seal Manufacturer
#1	FC-1	Shamban
#2	FC-2	Greene, Tweed

Fluid flow to cylinders #1 and #2 was controlled by 8000 psi direct drive (single stage) electrohydraulic servo valves. Cylinder #1 was driven by a rotary spool valve, reference 14. Cylinder #2 was powered by two linear valves plumbed in parallel. The linear valves were originally procured for use on the roll and pitch AFCS actuators.

3.2.3 Load System

Each load module contained an industrial-type cylinder that opposed test actuator stroking through a bellcrank/linkage arrangement. Each cylinder had an individual load pressure level maintained by individual hydraulic control circuits. Fluid power for all circuits was provided by a 20 gpm hydraulic power supply operating at 2300 psi using MIL-H-6083 fluid, Figure 26. The power supply was located outside the LHS simulator area to reduce noise.

3.3 TEST HARDWARE

3.3.1 Major 8000 psi Components

Pumps, actuators, and reservoirs were considered major components. Table 1 lists these items and provides part number, manufacturer, and design features. Photographs of installed components are also listed on Table 1.

Photographs of disassembled actuators are presented in Appendix D. Assembly drawings of the spoiler, roll feel isolation and leading edge flap actuators are also presented in Appendix D. Assembly drawings of all other major components are included in reference 11.

An AHT-63 portable hydraulic test stand was converted to operate at 8000 psi by replacing 3000 psi components with 8000 psi components, Figure 28. Table 1 gives pertinent information on the GSE.

3.3.2 Minor 8000 psi Components

Minor components are listed on Table 2. Part number, manufacturer, and design features are given for each item. Photographs of the components are also listed on Table 2. Components provided at no cost to the LHS program are indicated by * on Table 2.

TABLE 1. Major 8000 psi components

DESCRIPTION	FIG. NO.	PART NO.	QUANTITY	SYSTEM/ LOCATION	MANUFACTURER FSCM NO.	DESIGN FEATURES
ACTUATOR, RUDDER	17	8696-587100	1	FC-1&2, TAIL	ROCKWELL 89372	1. DUAL TANDEM 2. BALANCED AREAS 3. 2-STAGE ROD SEALS 4. FIXED BODY
ACTUATOR, SPEED BRAKE	21	83-00201	1	FC-1, FWD. FUSE.	VOUGHT 80378	1. SINGLE CYLINDER 2. UNBALANCED AREAS 3. 1-STAGE ROD SEAL 4. RETRACT LOCK
ACTUATOR, UNIT HORIZONTAL TAIL	15	83-00211	2	FC-1&2, TAIL	VOUGHT 80378	1. DUAL TANDEM 2. UNBALANCED AREAS 3. 2-STAGE ROD SEALS 4. FIXED BODY
ACTUATOR, AILERON (SEE FOOTNOTE[1])	11	83-00221	1	FC-1&2 LH WING	VOUGHT 80378	1. DUAL TANDEM 2. UNBALANCED AREAS 3. 2-STAGE ROD SEALS 4. MOVING BODY
ACTUATOR, AFCS	20	83-00231, 56E-201 (SERVO VALVE)	1	FC-1, TAIL	VOUGHT, MOOG 80378, 94697	1. DUAL PARALLEL 2. BALANCED AREAS 3. 1-STAGE ROD SEAL 4. DIRECT-DRIVE E-H SERVO VALVE
ACTUATOR, ROLL FEEL ISOLATION	19	83-00251	1	FC-1&2 CENTER FUSE.	VOUGHT 80378	1. DUAL TANDEM 2. BALANCED AREAS 3. 2-STAGE ROD SEALS 4. MOVING BODY 5. SHRINK-FIT CONTROL VALVE
ACTUATOR, LEADING EDGE FLAP	23	83-00261	4	FC-2 LH WING	VOUGHT 80378	1. SINGLE CYLINDER 2. UNBALANCED AREAS 3. 1-STAGE ROD SEAL 4. RETRACT AND EXTEND LOCKS
ACTUATOR, SPOILER/ DEFLECTOR	13	83-00271	1	FC-1&2 LH WING	VOUGHT 80378	1. DUAL TANDEM 2. UNBALANCED AREAS 3. 2-STAGE ROD SEALS 4. MOVING BODY 5. SHRINK-FIT CONTROL VALVE
PUMP	27	PV3-047-2	S/N 346581 348168 346580	FC-1 FC-2 "SPARE"	VICKERS 62983	1. IN-LINE PISTON 2. PRESSURE COMPENSATED 3. VARIABLE DELIVERY 4. 10 GPM @5900 RPM
RESERVOIR	9, 10	83-00241	2	FC-1 & 2, CENTER FUSE.	VOUGHT 80378	1. BOOTSTRAP DESIGN 2. 320 IN^3 CAPACITY 3. RESERVOIR PRESS.: 90 PSI
GROUND SUPPORT EQUIPMENT	28	AHT-63MOD	1	--	UMC 22680	1. 8 GPM @8000 PSI 2. 3 MICRON FILTRATION 3. 50 HP 440 VAC MOTOR 4. 15 FT HOSES WITH QUICK DISCONNECTS 5. DISCHARGE PRESSURE & FLOW ADJUSTABLE
SEAL TEST FIXTURE	25	4252-03 (FIXTURE) 50E-489 (ROTARY VALVE) 56E-201 (LINEAR VALVE)	1	FC-1&2 RH WING	ROCKWELL 89378 MOOG 94697	1. TEST SEALS: 4 2-STAGE UNVENTED ROD SEALS 2. DRIVEN BY SINGLE STAGE 8000 PSI SERVO VALVES

[1]FC-1 AND FC-2 CYLINDER BORES WERE DAMAGED IN A PRIOR TEST BY PISTON SEALS CONTAINING STEEL BACKUP RINGS. THE CYLINDERS WERE HONED IN AN ATTEMPT TO ELIMINATE BORE SCORING. ONLY FC-2 COULD BE REPAIRED. FABRICATION OF A NEW AILERON ACTUATOR BODY IS CURRENTLY IN WORK. FC-1 SECTION OF THE AILERON ACTUATOR WAS THEREFORE INOPERATIVE THROUGHOUT SIMULATOR TESTING REPORTED HEREIN.

TABLE 2. Minor 8000 psi components

DESCRIPTION	FIG. NO.	PART NO.	QUANTITY	SYSTEM/ LOCATION	MANUFACTURER, FSCM NO.	DESIGN FEATURES
ACCUMULATOR	29	3321471	1	FC-2 POWER MODULE	BENDIX ELECTRODYNAMICS 77068	1. PISTON TYPE 2. MAX. OIL VOL: 9 IN^3 3. MIN GAS VOL: 2 IN^3
CHECK VALVE	27	P4-858	1	FC-1 PUMP	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -8
CHECK VALVE	27	95201-5	1	FC-2 PUMP	GAR KENYON 26044	1. STANDARD DESIGN 2. SIZE: -8
CHECK VALVE	30	95200-5	1	FC-1 POWER MODULE	GAR KENYON 26044	1. STANDARD DESIGN 2. SIZE: -8
CHECK VALVE	29	95202-5	1	FC-2 POWER MODULE	GAR KENYON 26044	1. STANDARD DESIGN 2. SIZE: -8
CHECK VALVE	29 *	P2-858	1	FC-2 PRESSURE REGULATOR	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -8
CHECK VALVE	--	P9-858	2	FC-1&2 RUN AROUND	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -6
CHECK VALVE	30	P11-858	1	FC-1 SPEED BRAKE	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -4
CHECK VALVE	15	P8-858	4	LH&RH UHT ACTUATOR	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -4
CHECK VALVE	--	P1-858	2	RUDDER ACTUATOR	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -3
CHECK VALVE	30	P1-858 P10-858	1 1	FC-1 SPEED BRAKE	CIRCLE SEAL 91816	1. STANDARD DESIGN 2. SIZE: -3
FILTER	9, 10	AD-A640-83Y1	2	FC-1&2 POWER MODULE	AIRCRAFT POROUS MEDIA 18350	1. RATED FLOW: 10 GPM 2. FILTRATION: 5u ABS. 3. TITANIUM CONSTR.
FITTINGS		D11XXXXXXX			DEUTSCH 14798	1. EXTERNALLY SWAGED 2. PERMANENT AND SEPARABLE FITTINGS 3. LIP SEAL TYPE SEPARABLE FITTINGS
	*	3P00101-3 3P02121-8			RAYCHEM 34964	1. HEAT SHRINKABLE COUPLING 2. PERMANENT CONNECTION ONLY
		R44XXX-XX MR54XXX-XX			RESISTOFLEX 50599	1. INTERNALLY SWAGED 2. SEPARABLE CONNECTION ONLY 3. LIP SEAL TYPE SEPARABLE FITTING
		RFH5003-18 RFH5005-18			ROSAN 83324	1. TITANIUM CONSTR. 2. O-RING SEAL
FLUID	--	MIL-H-83282 A/B	3.2 GAL/ SYSTEM	FC-1&2	ROYAL LUBRICANTS 07950	1. SYNTHETIC HYDRO-CARBON 2. FIRE RESISTANT
HOSE	27 *	F37404008 -0300	2	FC-1&2 PUMP	TITEFLEX 78570	1. STEEL & NON-METALLIC REINFORCEMENT BRAIDS 2. SIZE: -8
HOSE	11 *	DE6964-3 -0282	2	FC-2 AILERON ACTUATOR	AEROQUIP 00624	1. KEVLAR REINFORCEMENT BRAID 2. SIZE: -3
HOSE	*	28404003-0214	4	FC-1&2 SPOILER & RFI ACTUATORS	TITEFLEX 78570	1. KEVLAR REINFORCEMENT BRAID 2. SIZE: -3 3. USED TO REPLACE FAILED COIL TUBES
MANIFOLD	-- 30	8696-581002 8696-581201	1 1	FC-1 POWER MODULE	ROCKWELL 89372	1. STEEL CONSTR. 2. ROSAN FITTINGS
PRESSURE GAGE	10	1218-63-1	1	FC-2 POWER MODULE	QED 24708	1. MINIATURE SIZE 2. MULTI-TURN HELICAL BOURDON TUBE

TABLE 2. (continued)

DESCRIPTION	FIG. NO.	PART NO.	QUANTITY	SYSTEM/ LOCATION	MANUFACTURER, FSCM NO.	DESIGN FEATURES
PRESSURE SNUBBER	--	95239	2	FC-1&2 POWER MODULE	GAR KENYON 26044	1. CONVENTIONAL DESIGN
PRESSURE TRANSMITTER	9, 10	18-2143	2	FC-1&2 POWER MODULE	COURTER 96774	1. SYNCHRO-TYPE (SIMILAR TO MS28005 -8) 2. MULTI-TURN HELICAL BOURDON TUBE
QUICK DISCONNECT	9 27	AE80943H AE81214H AE81215H	2 2 2	FC-1&2 POWER MODULE	AEROQUIP 00624	1. CONVENTIONAL DESIGN 2. THREE DIAMETRAL STATIC SEALS
RELIEF VALVE	30 29	1257A 1258	1 1	FC-1&2 POWER MODULE	PNEUDRAULICS 06177	1. CONVENTIONAL DESIGN 2. ONE DIAMETRAL STATIC SEAL
RESTRICTOR	30	REFX0380250AB	1	FC-1 SPEED BRAKE	LEE 92555	1. 2-WAY RESTRICTOR 2. MULTI-STAGE ORIFICES 3. 4 GPM @7800 PSID
RESTRICTOR	23	95461-2	1	FC-2 L.E. FLAP OUTBOARD RETRACT	GAR KENYON 26044	1. 1-WAY RESTRICTOR 2. 2.2 GPM @ 7800 PSID
RESTRICTOR	--	95462	2	FC-2 L.E. FLAP EXTEND	GAR KENYON 26044	1. 2-WAY RESTRICTOR 2. 1.17 GPM @7800 PSID
RESTRICTOR	--	95461-1	1	L.E. FLAP INBOARD RETRACT	GAR KENYON 26044	1. 1-WAY RESTRICTOR 2. 1.17 GPM
SEALS	* * *	SEE APPENDIX C FOR LIST OF DYNAMIC SEALS			CONOVER 07060 GREENE, TWEED 72902 SHAMBAN 25220	1. BACKUP RINGS 1. TEE SEALS 2. CAPPED G-T RING SEALS 1. DOUBLE DELTA SEALS 2. PLUS SEALS
SOLENOID VALVE	30 --	3321472 (4-WAY VALVE) 3321473 (3-WAY VALVE)	1 1	FC-1 SPEED BRAKE AFCS PITCH ACTUATOR	BENDIX 77068	1. CONVENTIONAL DESIGN 2. 28 VDC, PILOT OPERATED 3. RATED FLOW: 4-WAY 4.5 GPM 3-WAY 1.4 GPM 4. STEEL HOUSING
SOLENOID VALVE	29 20 --	305100 (2-WAY VALVE) 306750 (3-WAY VALVE) 306700 (4-WAY VALVE)	1 1 1	FC-2 POWER MODULE FC-1 AFCS YAW ACT'R FC-2 L.E. FLAP	PARKER-BERTEA 82106	1. CONVENTIONAL DESIGN 2. 28 VDC, PILOT OPERATED 3. RATED FLOW: 2-WAY 1.4 GPM 3-WAY 1.4 GPM 4-WAY 4.5 GPM 4. ALUMINUM HOUSING
SWIVEL	21	L38910 L39010	1 1	FC-1 SPEED BRAKE	LOURDES 01178	1. CONVENTIONAL DESIGN 2. RATED FLOW: 4 GPM 3. 2 DIAMETRAL SEALS
TUBING	--	LHS-8042A			KAWECKI-BERYLCO 61452	1. 3 AL-2.5V TITANIUM 2. TUBE SIZES: 3/16X.020, 1/4X.026, 5/16X.032, 3/8X.038, 1/2X.051
TUBING, COIL	13 13 13 13	83-00287-1 83-00287-3 83-00288-1 83-00288-3	1 1 1 1	FC-1 P SPOILER FC-1 R SPOILER FC-2 P SPOILER FC-2 R SPOILER	VOUGHT 80378	1. 3AL-2.5V TITANIUM 2. TUBE SIZE: 3/16X.035 3. NESTED COILS 4. DEUTSCH FITTINGS
TUBING, COIL	19 19 19 19	83-00283-1 83-00283-3 83-00284-1 83-00284-3	1 1 1 1	FC-1 P RFI FC-1 R RFI FC-2 P RFI FC-2 R RFI	VOUGHT 80378	1. 3AL-2.5V TITANIUM 2. TUBE SIZE: 3/16X.035 3. DEUTSCH FITTINGS 4. TYPE: NESTED COILS (283) TRI-COILS (284)

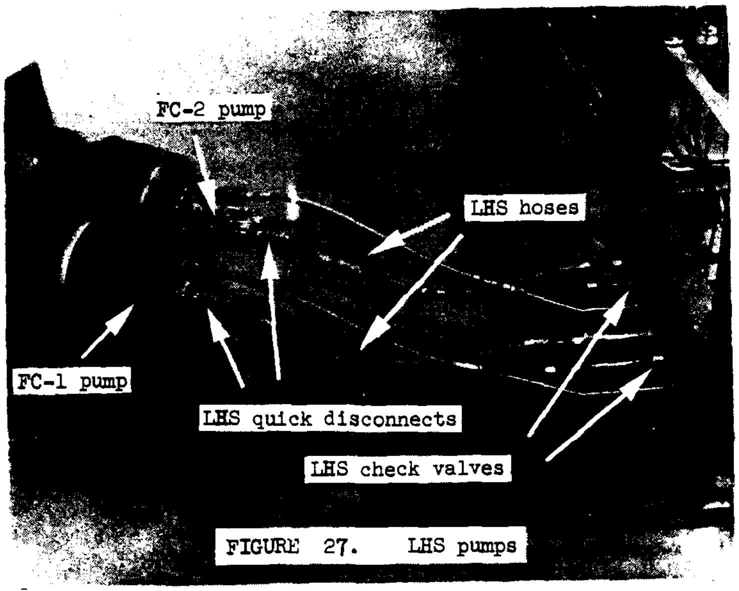


FIGURE 27. LHS pumps

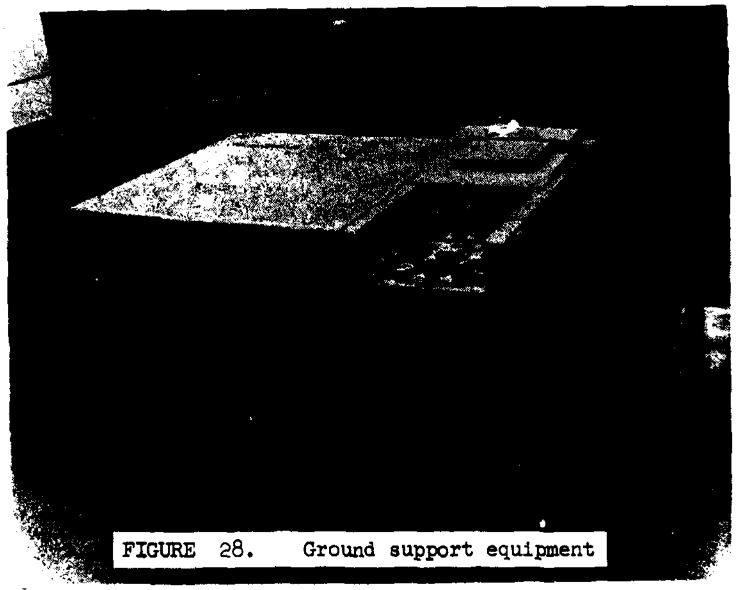


FIGURE 28. Ground support equipment

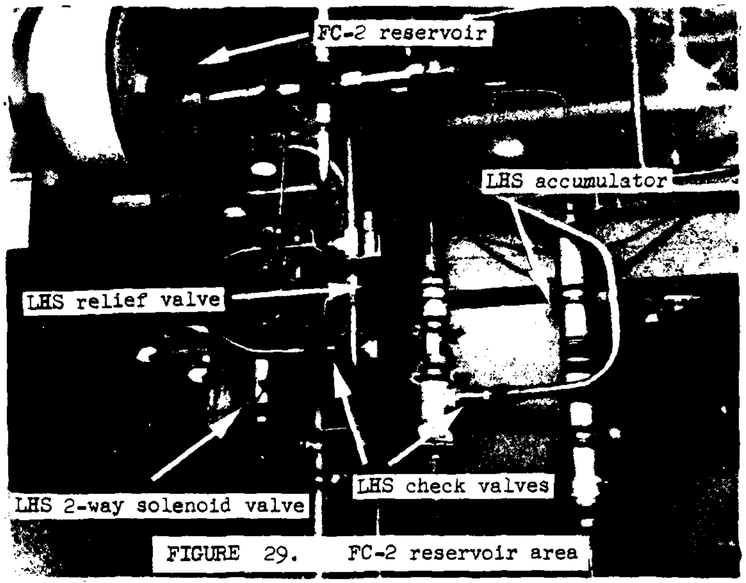


FIGURE 29. FC-2 reservoir area

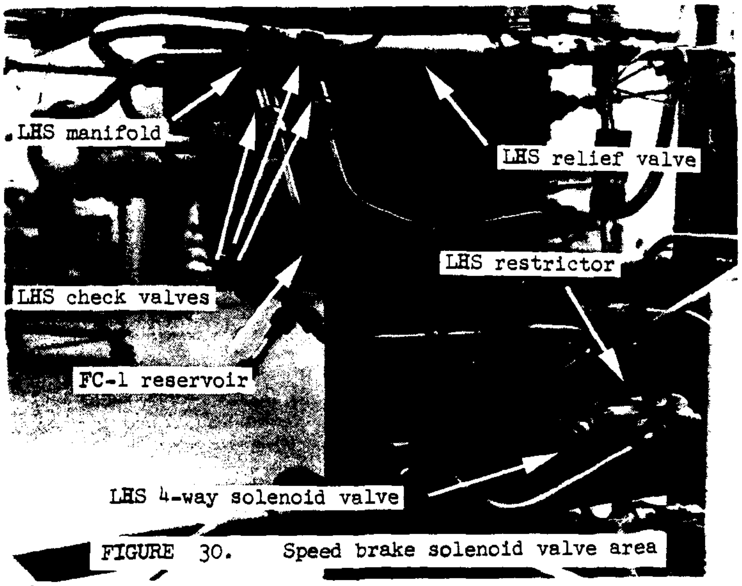


FIGURE 30. Speed brake solenoid valve area

3.4 INSTRUMENTATION

3.4.1 Controls

Simulator controls are housed in two consoles located near the simulator tail, Figure 31. The control console has the following indicators, controls, and safety provisions:

Controls	Indicators	Safety Provisions
Pump speed	Pump rpm	Over-temperature
Fluid temperature	Fluid flow	Low fluid
Electrical power	Fluid temperature	(8000 psi and 2300 psi systems)
Flap/speed brake switches	System pressure (synchros)	Pressure interlock (8000 psi must be on before 2300 psi)

The programmer console permits either manual or automatic operation of the simulator. Manual control is by a "pilot" type joy stick for the roll and pitch axes and a foot pedal for yaw inputs. Automatic operation is by means of a mechanical timer/programmer that applies various sinusoidal inputs for 5 minute periods during a 2 hour simulated flight, reference Section 4.5.1. The programmer console has the following:

Manual/automatic switches
Load on-off switches
Step indicator (0 to 24)
Timer/programmer
Load/stroke bias controls
Load/stroke amplitude controls
Cycling rate controls
Pilot's stick
Signal monitoring oscilloscope

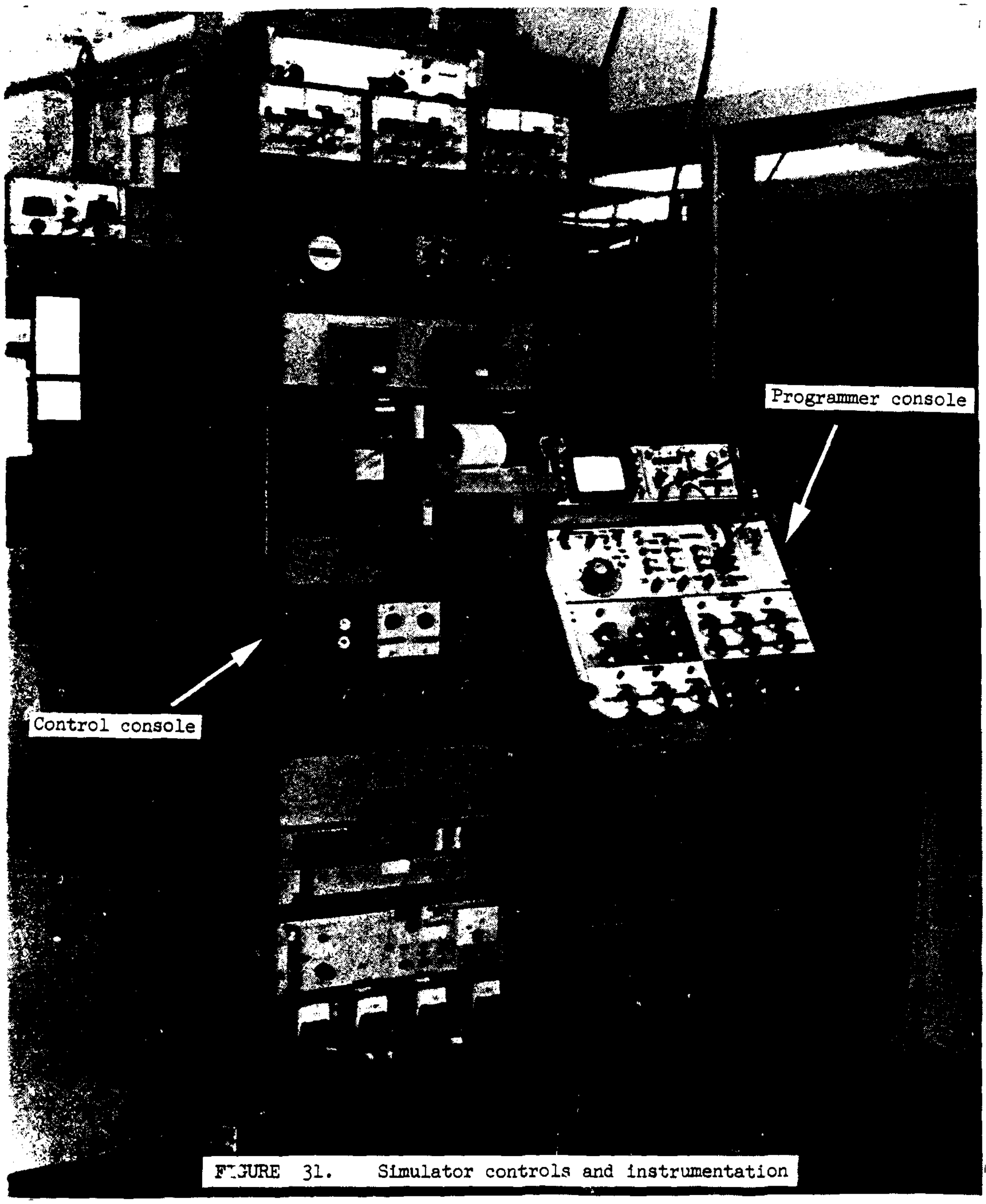


FIGURE 31. Simulator controls and instrumentation

3.4.2 Monitoring

Parameters monitored visually are listed below. Transducer locations are given in Table 3.

Parameter	Quantity	Transducer	Readout
Temperature	26	Thermocouple	Programmable data logger
Pressure	7		Dial pressure gage
Flow	12	Turbine flowmeter	Frequency counter
Pump speed	1	Magnetic pickup	Frequency counter
Simulator running time	1	Clock	Digital time totalizer

3.4.3 Dynamic Data

3.4.3.1 Oscillograph Data. A multichannel oscillograph with direct readout was used for transient pressure investigations. Light beam type galvanometers with 1000 Hz response capability were installed in the oscillograph. Film speeds up to 40 in/sec were used to provide high resolution. The transducers were bonded strain gage type pressure pickups.

3.4.3.2 Oscilloscope Data. System pressure dynamics excited by pump ripple were displayed on an oscilloscope screen and photographed. Oscilloscope bias adjustments permitted examination of small (<100 psi) pressure fluctuations superimposed on system pressure (8000 psi). The oscilloscope had dual beams which permitted simultaneous comparison of two pressures. Bonded strain gage type pressure transducers with a bandwidth of 20,000 Hz were the signal source. Provisions were built into the simulator plumbing at selected locations throughout FC-1 and FC-2 systems to permit installation of the transducers. The oscilloscope was used in the system integration search for hydraulic resonance and examination of pump ripple.

TABLE 3. Transducer locations

PARAMETER	SYSTEM	LOCATION	TRANSDUCER TYPE
Temperatures			
T1	FC-1	Pump inlet	Chromel-alumel thermocouple
T2	FC-1	Pump case drain	
T3	FC-1	LH UHT return	
T4	FC-1	RH UHT return	
T5	FC-1	Rudder return	
T6	FC-1	LH aileron return	
T7	FC-1	LH spoiler/deflector return	
T8	FC-1	Speed brake return	
T9	FC-1	AFCS yaw return	
T10	FC-1	System return	
T11	FC-2	Pump inlet	
T12	FC-2	Pump case drain	
T13	FC-2	LH UHT return	
T14	FC-2	RH UHT return	
T15	FC-2	Rudder return	
T16	FC-2	LH aileron return	
T17	FC-2	LH spoiler/deflector return	
T18	FC-1	Seal test fixture	
T19	FC-2	Seal test fixture	
T20	FC-2	System return	
T21	--	Ambient air	
T22	Load	System return	
T23	FC-1	Heat exchanger inlet	
T24	FC-1	Heat exchanger outlet	
T25	FC-2	Heat exchanger inlet	
T26	FC-2	Heat exchanger outlet	
Pressures			
P1	FC-1	Pump inlet	Dial pressure gage
P2	FC-1	Pump case drain	
P3	FC-1	Pump discharge	
P4	FC-2	Pump inlet	
P5	FC-2	Pump case drain	
P6	FC-2	Pump discharge	
P7	Load	Pump discharge	
Flows			
F1	FC-1	Pump case drain	Turbine flowmeter
F2	FC-2	Pump case drain	
F3	FC-1	Pump inlet	
F4	FC-2	Pump inlet	
F5	FC-1	LH UHT actuator return	
F6	FC-2	Rudder actuator return	
F7	FC-1	LH aileron actuator return	
F8	FC-2	Seal test fixture return	
F9	FC-1	Speed brake actuator return	
F10	FC-2	RH UHT actuator return	
F11	FC-2	Spoiler/deflector return	
F12	Load	System return	

NOTE: INSTRUMENTATION USED IN FINAL TEST SYSTEM, SEE FIGURE 5.

3.4.3.3 Spectrum Data. Analysis of pressure wave dynamics was accomplished using ubiquitous signal processing equipment. Both real time and instant spectrum analysis displays were obtained. Readout was on an interactive digital x-y plotter. Piezoelectric transducers with 100,000 Hz response capability sensed pressure dynamics. This equipment was used for math model verification and pressure harmonics testing.

3.4.4 Data Logs

Laboratory logs of all tests and operations were maintained. Due to the scope and duration of testing, the data were segregated to facilitate information retrieval. Major file categories were:

- Pump performance
- Component performance
- Mission/profile test log
- Individual component logs
- Daily work logs
- Malfunctions and failures

4.0 SIMULATOR TESTS

4.1 PROOF PRESSURE

Two types of proof tests were conducted on the newly fabricated hydraulic systems. First, pressure lines alone, i.e., tubing, fittings, and hoses were proofed at 16,000 psi. Second, the complete pressure system, with all components installed, was proofed at 12,000 psi. Since system fabrication was done in stages, FC-1 in 1982 and FC-2 in 1984, two proof tests were performed.

4.1.1 Test Procedures

4.1.1.1 Transmission Lines. Temporary lines were installed to replace removed components. All pressure tubing in the fuselage and LH wing were proofed simultaneously using a 0.2 gpm hydraulic power supply to fill lines and build pressure up to 8000 psi. A hand pump was then used to increase pressure to 16,000 psi. Proof pressure was held for 2 minutes, released, then applied again for 2 minutes.

4.1.1.2 System. This test was performed on the complete system with all components installed except the pump and with the relief valve return port plugged. Since approximately 0.7 gpm of internal leakage was expected to occur during the test, a hand pump could not be used. Instead, a reciprocating hydraulic pressure intensifier applied the required 12,000 psi. The total system was proofed for 5 minutes with all actuators extended, then for 5 minutes with all actuators retracted. The system proof test was performed after hydraulic fluid cleanup discussed in Section 4.2.

4.1.2 Results

Proof test results were completely satisfactory. No failures occurred and no leakage was observed during either the test conducted in 1982 or in the 1984 test.

4.2 SYSTEM INTEGRATION

Initial operation of the simulator was accomplished by employing tasks properly sequenced to prevent damaging components. Two areas were involved: 1) start-up and 2) operation checks. Tasks described in this section were conducted with a one pump system, Figure 4.

4.2.1 Start-Up Procedures

4.2.1.1 Fluid Clean-Up. Hydraulic fluid cleanliness was essential to prevent component damage. All actuator pressure and return lines were interconnected to form a circuit and by-pass the actuators. Filter elements were removed from the pressure and return filters. A 3000 psi laboratory pump and a laboratory filter were temporarily installed in the simulator system. Fluid was circulated through system tubing for 4 hours and a fluid sample was drawn to check contamination. When the contamination level met NAS 1638, Class 8 requirements, the temporary pump and filter were removed and the system was restored to its original configuration.

4.2.1.2 Initial Startup. First-time operation of the hydraulic system was done with all actuators unloaded and with 1000 psi applied. This was accomplished by disconnecting all actuator piston rod ends and by partially opening a pressure unloading valve in FC-1 power module. With the test pump running and the system pressurized at 1000 psi, visual checks were made for external leaks and loose fittings. After correcting all leaks, system pressure was increased to 8000 psi and further leak checks were made.

4.2.1.3 Rigging. Operation of the simulator actuators at 8000 psi could physically damage certain elements if rigging is improper. Actuator length and stroke requirements were the same as for an aircraft installation. Each actuator was rigged separately to obtain the specified dimensions. With the piston rod disconnected from the load module and 8000 psi applied, each actuator was manually operated full extend and retract. Overall lengths were measured, and the rod ends adjusted as required. Stops on the actuator input control linkage were then adjusted to provide specified working strokes.

4.2.2 Operation Checks

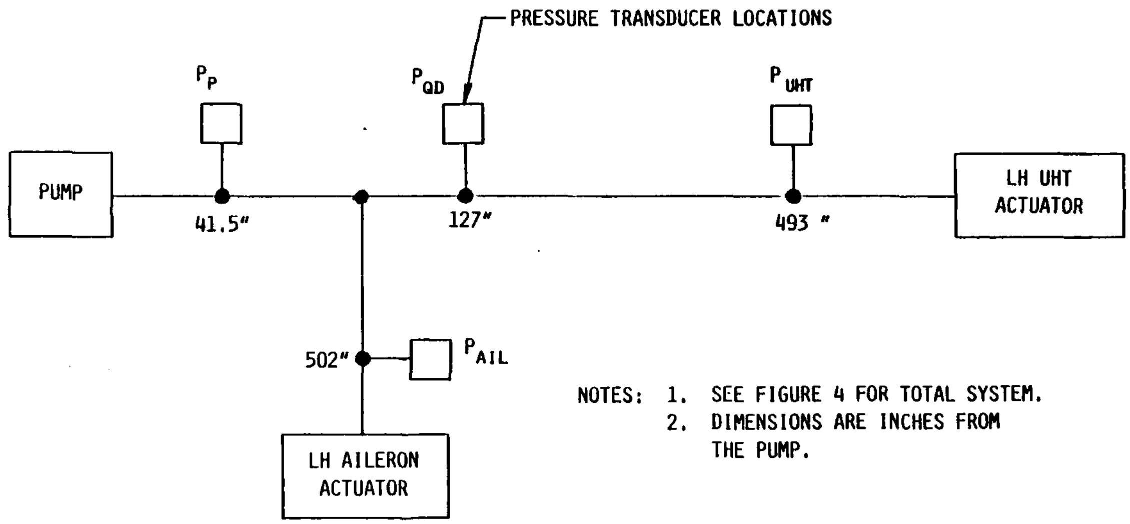
4.2.2.1 Resonance Survey. The first check was to determine if any operating conditions existed which could harm components. A primary cause of such damage is pump induced hydraulic resonance. A survey was made for resonance using pressure transducers and an oscilloscope to observe pressure ripple. Transducer locations are shown on Figure 32. The investigation was conducted over a pump speed range of 3400 to 5900 rpm and at two temperatures -- +140 and +200°F pump inlet fluid. Typical data are presented in Figures 33 and 34.

No damaging resonance was found. Pressure ripple was highest near the pump and very low at the UHT and aileron actuators. Peak-to-peak values are summarized on Table 4.

4.2.2.2 Operating Stability. The flight control actuators were cycled with various combinations of 2%, 10%, and 50% stroke over the speed range of the pump. The speed brake and L.E. flap actuators were also cycled. Pump response and control stability were satisfactory.

4.3 BASELINE

Tests were performed to determine the range and distribution of simulator fluid temperatures, pressures, and flows. Two basic operating conditions were examined: 1) steady-state and 2) mission/profile cycling (see Section 4.5). Data were taken on the initial test system (ref. Figure 4) and on the final test system (ref. Figure 5). Only data considered pertinent is presented.



NOTES: 1. SEE FIGURE 4 FOR TOTAL SYSTEM.
2. DIMENSIONS ARE INCHES FROM THE PUMP.

FIGURE 32. Transducer locations for resonance survey

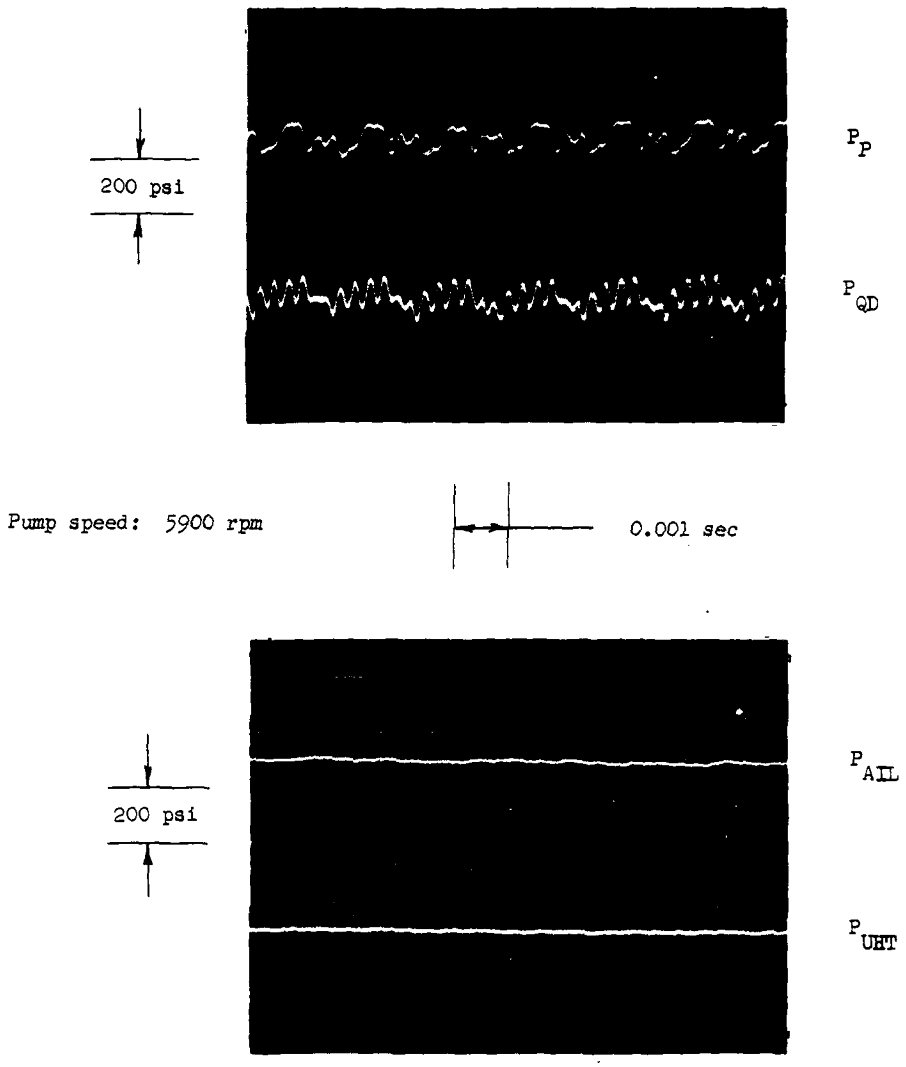


FIGURE 33. Resonance survey data, +140°F

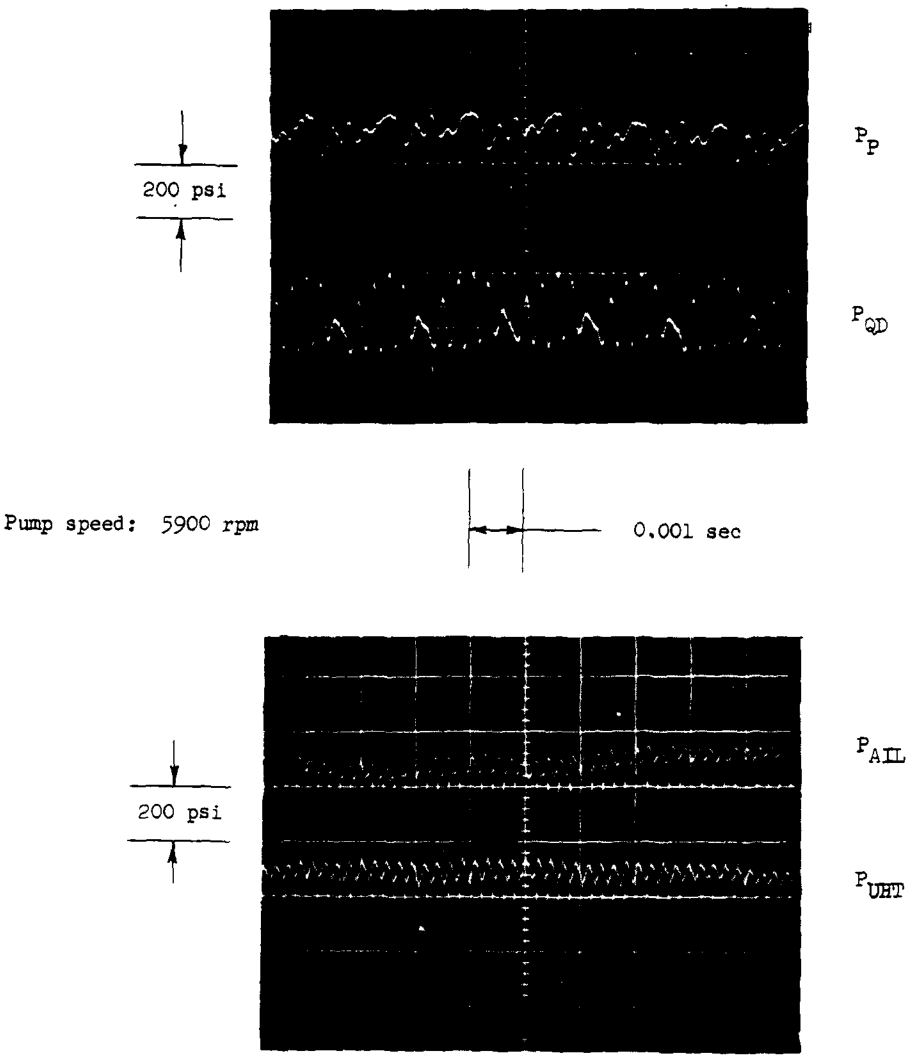


FIGURE 34. Resonance survey data, +200°F

TABLE 4. Pump ripple amplitude

PUMP INLET FLUID TEMP., °F	PUMP SPEED, RPM	PUMP RIPPLE, PSI			
		P_P	P_{QD}	P_{AIL}	P_{UHT}
+140	3400	±60	±50	±20	±10
	3900	±70	±50	±10	0
	4400	±80	±100	±10	±10
	4900	±50	±90	±10	±10
	5400	±90	±125	0	0
	5900	±60	±80	0	0
+200	3400	±125	±80	±50	±20
	3900	±125	±125	±20	±20
	4400	±125	±150	±30	±60
	4900	±100	±130	±30	±30
	5400	±110	±150	±40	±40
	5900	±80	±130	±50	±50

NOTES: 1. MAXIMUM ALLOWABLE PRESSURE RIPPLE IS ±200 PSI, REFERENCE SPECIFICATION LHS-8810-1

2. DATA IS FOR ONE PUMP CONFIGURATION, FIGURE 4.

4.3.1 Initial Test System

Steady-state stabilized temperatures resulting from operation with pump suction fluid maintained at +200°F are shown on Table 5. A small oil-to-water heat exchanger in the pump case drain line and a temperature controller were used to maintain the +200°F. All tests were begun with suction fluid near room temperature except as noted in Table 5. The roll, pitch, and yaw axes were operated with synchronized inputs. Pump case drain temperature never exceeded +260°F. Actuator return fluid was generally less then +240°F. Heat removed by the heat exchangers ranged from 100 to 300 BTU/min depending upon operating conditions. Heat removed by conduction, convection, and radiation was considered to approximate that which might occur in an A-7E operating on the ground during an +80°F day. The range and distribution of fluid temperatures observed were satisfactory.

Pump flows measured during mission/profile cycling are listed on Table 6. System fluid was at room temperature at the beginning of Step 1. Pump suction temperature was not allowed to exceed +200°F during the 2 hour course of the test. Maximum discharge flow occurred in Step 17 when the pitch axis was operating at 50% and the yaw axis at 100%. Maximum case flow occurred at the start of Step 13 following operation of the pitch axis at 100% and the yaw axis at 50%.

4.3.2 Final Test System

Steady-state stabilized temperatures resulting from operation under various conditions are shown on Table 7. The roll, pitch, and yaw axes were cycled simultaneously with either null, 2%, or 10% inputs, but cycling was not synchronized. The LH aileron FC-2 ports were plumbed into FC-1 system; the FC-1 ports were not used (See note on Table 1). Temperature range and distribution were considered satisfactory.

Heat removed by the oil-to-water heat exchangers in FC-1 and FC-2 system case drain lines differed significantly. The difference was attributed to configuration dissimilarities. FC-1 power module is relatively compact, Figure 9. FC-2 power module is much larger, Figure 10, and contains nearly 40 feet of additional tubing in the pump case drain line. The extra tubing length simulates a cooling loop employed in the A-7E. Heat removed for the stabilized conditions shown on Table 7 are given below:

Heat Removed, BTU/min

Suc. Temp, °F	140	140	200	150	200	150	200	200	200
Pump rpm	3400	5900	5900	3400	3400	5900	5900	3400	5900
Cycling Mode	null	null	null	2%	2%	2%	2%	10%	10%
FC-1	210	207	93	291	178	323	204	400	400
FC-2	27	60	13	152	43	154	63	185	229

TABLE 5. Steady-state temperatures, initial test system

	OPERATING CONDITIONS					
SUCTION TEMP., °F PUMP RPM CYCLING MODE	200 3400 NULL	200 5900 NULL	200 3400 10%	200 5900 10%	200 3400 50%	200 5900 50%
STABILIZATION TIME, MIN	20[1]	30	18	14[2]	22	18
LOCATION						
Suction	205	197	202	198	198	199
Case Dr.	257	259	250	253	246	254
LH UHT	110	101	236	238	240	244
Rudder	84	73	206	210	204	200
LH Aileron[3]	73	73	74	74	73	71
LH Spoiler	96	87	171	179	151	169
Speed Brake	109	81	98	82	95	95
Yaw AFCS	74[4]	73[4]	117	140	117	140
System Return	217	218	206	205	202	203
Ambient Air	76	71	75	75	75	72

NOTES: 1. SUCTION FLUID TEMPERATURE +166°F AT START OF TEST

2. SUCTION FLUID TEMPERATURE +137°F AT START OF TEST

3. AILERON ACTUATOR NOT IN SYSTEM. NEEDLE VALVE INSTALLED BETWEEN FC-1 P&R ACTUATOR HOSES AND SET FOR 20 CC/MIN FLOW

4 AFCS SOLENOID VALVE "OFF"

TABLE 6. Pump flows, initial test system

MISSION/ PROFILE STEP NO.	DISCHARGE FLOW, GPM MIN.	STEADY	MAX.	CASE FLOW, AVG. GPM
1		.06		1.04
2		.26		1.11
3	3.04		3.32	1.05
4	3.01		4.92	1.09
5	2.35		2.96	1.11
6		.043		1.27
7	2.43		4.10	1.07
8	2.90		4.83	1.14
9	2.16		2.65	1.31
10	2.68		5.04	1.19
11	1.26		2.29	1.30
12	1.76		4.61	1.19
13		1.00		1.41
14		.85		1.27
15		.81		1.27
16	3.17		3.46	1.17
17	3.12		5.38	1.20
18	2.44		2.90	1.28
19	2.09		3.26	1.20
20	2.86		5.11	1.18
21	3.57		4.08	1.21
22	1.92		3.07	1.18
23	1.84		2.48	1.19
24	2.04		4.37	1.27

NOTES:
1. PUMP USED WAS S/N 346581 (FC-1)
2. SEE TABLE 13 FOR MISSION/PROFILE CYCLING DETAILS
3. SYSTEM AT ROOM TEMPERATURE AT START OF STEP 1.
4. DISCHARGE FLOW = SUCTION FLOW - CASE FLOW

TABLE 7. Steady-state temperatures, final test system

		OPERATING CONDITIONS								
SUCTION TEMP, °F PUMP RPM CYCLING MODE		140 3400 NULL	140 5900 NULL	200 5900 NULL	150 3400 2%	200 3400 2%	150 5900 2%	200 5900 2%	200 3400 10%	200 5900 10%
SYSTEM	LOCATION									
FC-1	Suction	142	143	197	159	203	150	200	201	202
	Case Drain	200	206	250	210	248	206	252	250	253
	LH UHT	119	127	173	200	237	189	238	245	245
	RH UHT	134	135	167	200	236	188	236	243	243
	Rudder	83	84	101	183	212	163	205	226	226
	LH Aileron	--	--	--	--	--	--	--	--	--
	LH Spoiler	146	147	101	165	196	152	195	193	192
	Speed Brake	87	90	93	84	101	88	104	90	82
	Yaw AFCS	61	69	72	155	174	138	174	179	178
	System Return	156	155	217	169	208	157	212	213	213
FC-2	Suction	144	145	195	151	202	151	201	203	202
	Case Drain	217	229	264	200	251	213	259	251	258
	LH UHT	107	118	152	191	236	187	236	245	245
	RH UHT	104	108	144	195	239	193	239	245	246
	Rudder	90	91	101	178	209	161	199	222	222
	LH Aileron	83	77	94	162	200	167	203	196	196
	LH Spoiler	108	113	148	142	176	145	181	176	177
FC-1	Seal Fixture	163	158	202	197	232	190	233	233	232
FC-2	Seal Fixture	--	--	--	--	224	186	226	--	--
	System Return	145	137	159	146	200	146	209	194	195
	Ambient Air	69	72	75	74	77	74	78	74	72
FC-1	Ht. Ex. In	199	204	248	208	247	205	250	248	250
	Ht. Ex. Out	152	162	231	138	209	132	210	157	156
FC-2	Ht. Ex. In	198	207	240	182	224	187	236	225	230
	Ht. Ex. Out	190	190	237	130	212	135	220	170	153

TABLE 8. Steady-state pressures and flows, final test system

		OPERATING CONDITIONS								
TEMP, °F PUMP RPM CYCLING MODE		140 3400 NULL	140 5900 NULL	200 5900 NULL	150 3400 2%	200 3400 2%	150 5900 2%	200 5900 2%	200 3400 10%	200 5900 10%
PRESSURES										
SYSTEM	LOCATION									
FC-1	Suction	102	99	102	99	98	99	99	96	96
	Case Drain	116	115	118	115	113	117	117	113	113
	Discharge	8100	8070	8010	8080	8020	8050	8010	8020	7980
FC-2	Suction	99	97	103	103	100	100	101	99	98
	Case Drain	121	122	127	123	123	123	126	124	125
	Discharge	8110	8100	8040	8120	8050	8100	8030	8030	8000
FLOWS										
FC-1	Suction	1.59	1.67	1.98	2.89	3.05	2.85	3.08	4.06	4.17
	Case Drain	1.25	1.37	1.47	1.16	1.28	1.24	1.39	1.21	1.31
	LH UHT	0+	0+	0+	.41	.46	.32	.36	1.01	1.01
	Rudder	0+	0+	0+	0+	0+	0+	0+	.10	.10
FC-2	Suction	*1.09	*1.15	1.44	*2.13	2.72	2.37	2.64	*3.39	*3.51
	Case Drain	.93	.98	1.16	.82	.98	.83	1.07	.93	1.02
	RH UHT	0+	0+	0+	.41	.42	.34	.36	.93	.93
	LH Aileron	0+	0+	0+	0+	0+	0+	0+	0+	0+
	LH Spoiler	0+	0+	0+	0+	0+	0+	0+	0+	0+

NOTES: 1. *FC-2 SEAL TEST FIXTURE NOT OPERATING

2. 0+ = FLOW TOO LOW FOR TURBINE FLOWMETER READOUT

Stabilized pressures and flows are presented on Table 8. All pressures and flows were considered satisfactory. The flowmeters used in actuator return lines were -8 size and had a flow measurement range of 0.2 to 6 gpm. Actuator null leakage and small stroke flow rates could therefore not be measured as indicated on Table 8. (Actuator null leakage checked during mission/profile testing was performed using a graduate and stopwatch. Leakage was usually less than 0.03 gpm (See Table 22).

4.4 DYNAMIC PERFORMANCE

4.4.1 Pressure Harmonics

4.4.1.1 Test Procedure. Pressure dynamics occurring in the discharge line near the pump were investigated. Two methods of pressure measurement were employed: 1) a piezoelectric transducer was teed into a line, and 2) a piezoelectric transducer was clamped on the outside of a line. The two methods were used to demonstrate transducer response correlation as well as provide simulator performance data. The data presented are for the final test system, Figure 5.

The transducer clamp-on device was designed and fabricated by NAAO-Columbus, Figure 35. The same piezoelectric transducer was used for both the clamp-on and tee-in arrangements. Pressure wave spectrum analysis and real time data display were performed by a dual channel fast fourier transform analyzer, Figure 36. Data presentation was accomplished with an interactive digital x-y plotter. A block diagram of the instrumentation is shown on Figure 37.

Four test configurations were evaluated, Figure 38. Installation of the female tee in configurations #2 and #4 added fluid volume at the pressure measurement location and influenced fluid dynamics slightly. Data for the four configurations was necessarily taken at different times because of plumbing differences. Although care was exercised to duplicate pump speed and fluid temperature conditions for each configuration, operating conditions were probably not identical.

4.4.1.2 Results. Selected examples of real time and instant spectrum data are presented in Appendix B. The data were taken with a pump discharge fluid temperature of +145°F and with all simulator actuators operating at null. A summary of peak-to-peak pump ripple is given on Table 9. As expected, pump ripple was the predominate harmonic mode. First and second harmonics generally had lower amplitudes than the fundamental. Occasionally pump yoke natural frequency (12 Hz) entered the spectrum. The maximum ripple found was 300 psi p-p; maximum allowable ripple is 400 psi p-p. Correlation of the clamp-on and tee-in transducer outputs was considered excellent for both the real time and spectrum data. See comparison data in Appendix B.

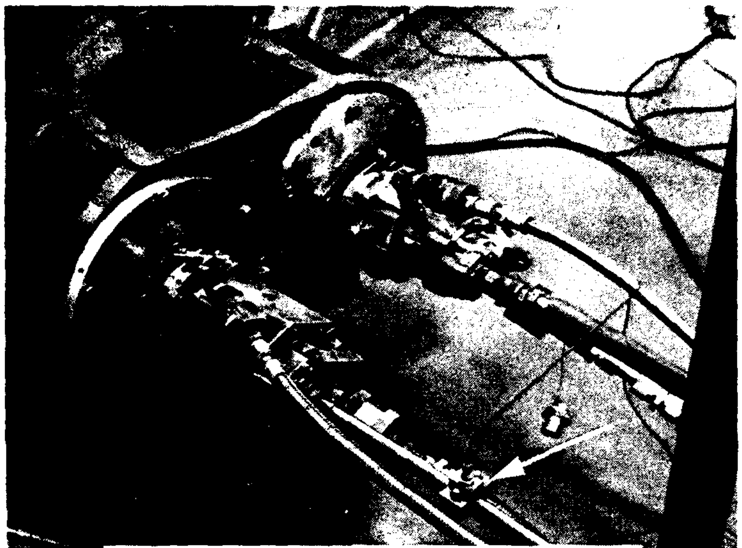


FIGURE 35. Clamp-on pressure transducer

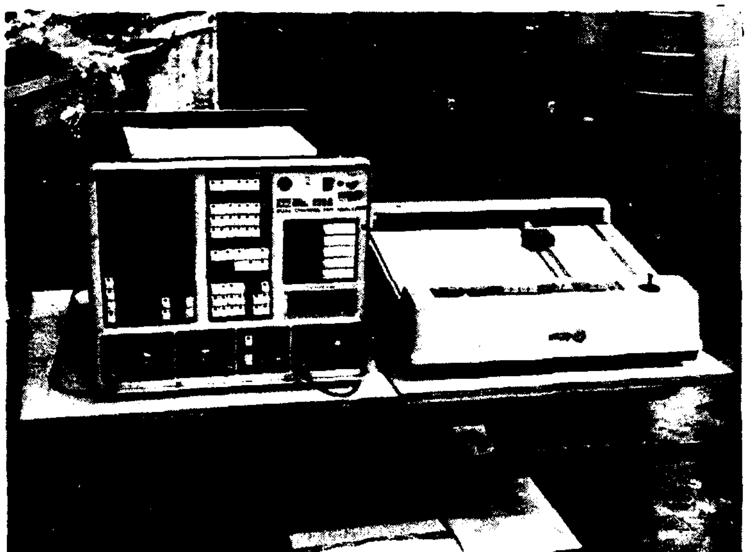
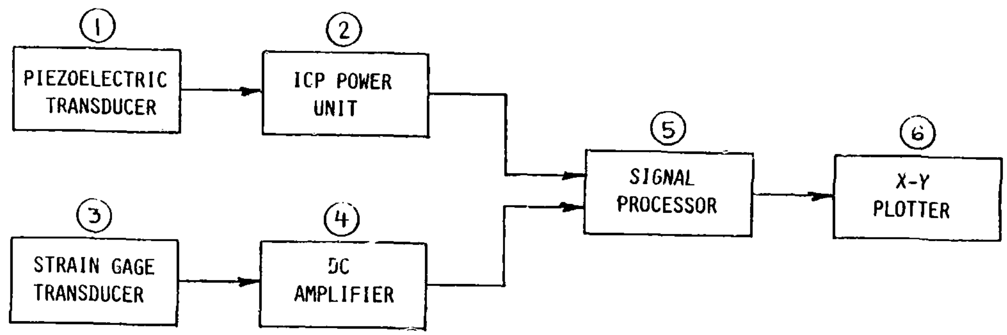


FIGURE 36. Pressure dynamics analysis instrumentation

1. PIEZOTRONICS M/N 108A02
2. PIEZOTRONICS M/N 484B
3. VIATRAN M/N 122FF76
4. BAY M/N 5503
5. NICOLET M/N 660A
6. TECTRONIX M/N 4662



NOTE: 3 USED TO CALIBRATE 1

FIGURE 37. Pressure wave harmonics instrumentation

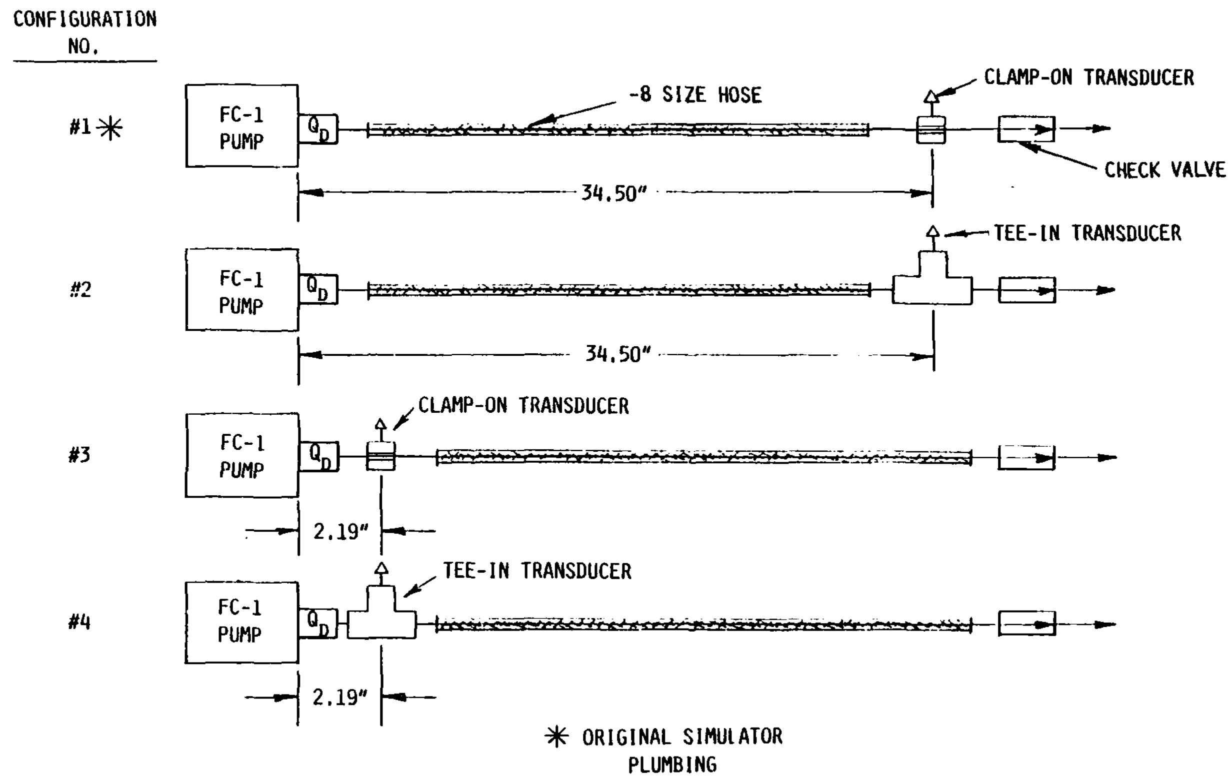


FIGURE 38. Pressure wave harmonics test configurations

TABLE 9. FC-1 pump ripple

Pump Speed, rpm	Pump Ripple, psi p-p Location, 2.19 in.	Location, 34.5 in.
2400	240	200
2800	300	180
3400	200	240
3500	270	260
4000	160	140
5885	250	150

4.4.2 Pressure Peaks and Transients

4.4.2.1 Test Procedure. Measurements were taken in the pressure and return systems to verify that pressure transients resulting from the operation of actuators and solenoid valves did not exceed design limits. The maximum allowable peak in the pressure system is 9600 psi (120% of operating pressure). The maximum allowable peak in the return system is 4000 psi (50% of operating pressure). The data presented are for the initial test system, Figure 4.

Two strain gage type pressure transducers were used to measure the transient peaks. One transducer was located immediately upstream of the component being operated, and one immediately downstream. Readout was on an oscillograph with 1000 Hz response capability. The transducers were relocated for measurements at other components.

4.4.2.2 Results. Operating conditions and resulting transient pressures are given on Table 10. All pressure peaks were acceptable except at the AFCS yaw actuator where an 11,700 psi surge occurred when a Bendix 3-way shut-offvalve was energized to power the actuator, Figure 39. The surge was caused by high fluid velocities being ported through the valve during the period of pressurizing the AFCS actuator to 8000 psi. The high velocities resulted from compressed system fluid suddenly expanding into a line filled with fluid at return pressure. The surge was eliminated, Figure 40, by installing a restrictor in the inlet port of the 3-way solenoid valve. The restrictor, rated at 2 gpm at 7800 psid, did not degrade AFCS actuator performance (maximum actuator flow is 0.5 gpm).

A similar surge investigation was conducted following fabrication of the two pump system when a Parker Bertea 3-way valve was used instead of the Bendix valve. This time the restrictor was installed in port 'C' (downstream of the valve). Results of this test, shown on Figures 62 and 63, were used to corroborate the math model HYTRAN program (see Section 5.3).

TABLE 10. Transient pressure peaks

COMPONENT	PUMP SPEED, RPM	SUCTION FLUID TEMP, °F	ACTUATOR LOAD	* OPERATING MODE	TRANSIENT PRESSURE PEAK, PSI P SUPPLY	P C1	P C2	P RETURN
Rudder, Actuator	3400	+140	None	1	8550			578
				2	8620			548
				3	8570			603
				4	8450			643
	5900	+200	None	1	8300			703
				2	8520			643
				3	8550			678
				4	8520			703
LH UHT Actuator	3400	+140	None	1	8560			446
				2	--			--
				3	8630			801
				4	--			--
	5900	+200	None	1	8560			476
				2	--			--
				3	8660			786
				4	--			--
AFCS Yaw Actuator	3400	+140	None	1	**			609
				2	**			579
				3	**			639
				4	**			634
				5	10990			719
				6	~100+			584
	5900	+200		1	**			679
				2	**			684
				3	**			724
				4	**			679
				5	11700			1143
				6	~100+			689
Spoiler Actuator	3400	+140	Full	1	8160			310
				3	8310			565
	5900	+200		1	8110			323
				3	8310			546
Solenoid Valve, Speed Brake Actuator	3400	+140	Full	7	8580	7990	4370	2370
				8	8170	100	8350	131
				9	8680	8290	1835	443
				10	8220	7910	100	141
				11	8420	7960	100	282
	5900	+200	Full	7	8630	8340	4600	2500
				8	8050	100	8270	131
				9	8450	8210	1825	181
				10	8140	7780	100	136
				11	8370	7890	100	282
Solenoid Valve, L.E. Flap Actuator	3400	+140	Full	7	9310	8590	203	1850
				8	8230	8330	100	131
				9	9560	354	8470	1400
				10	8290	100	8250	110
	5900	+200	Full	7	9090	8490	279	1750
				8	8180	8260	100	101
				9	9570	404	8500	1360
				10	8240	100	8170	100

*OPERATING MODES
1 10% retract to null (step input)
2 10% extend to null (step input)
3 50% retract to null (step input)
4 50% extend to null (step input)
5 3-way valve "off" to "on," actuator at null
6 3-way valve "on" to "off," actuator at null
7 Hold to extending (from full retraction)
8 Bottoming at full extend
9 Start of retraction (from full extension)
10 Bottoming at full retraction
11 Retract to hold (at full retraction)

**Data not meaningful since 3-way valve was de-energized to produce step input at actuator.

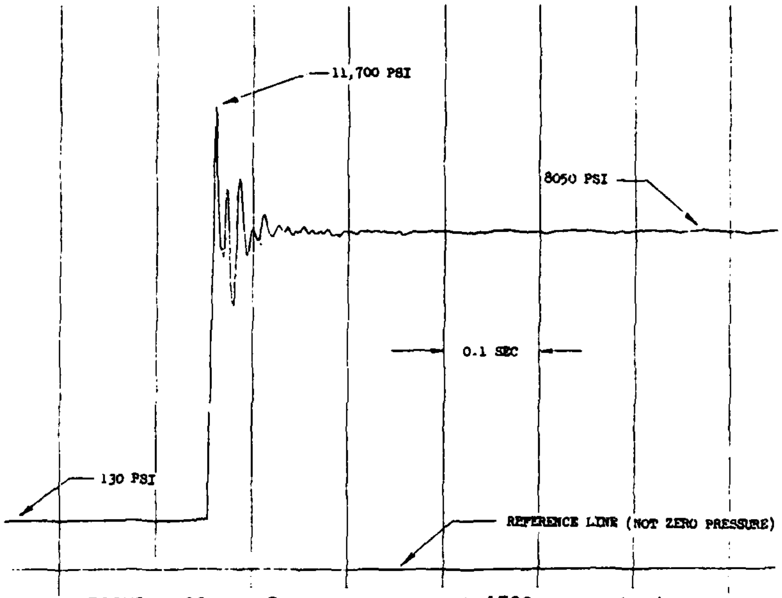


FIGURE 39. Pressure surge at AFCS yaw actuator with original plumbing configuration

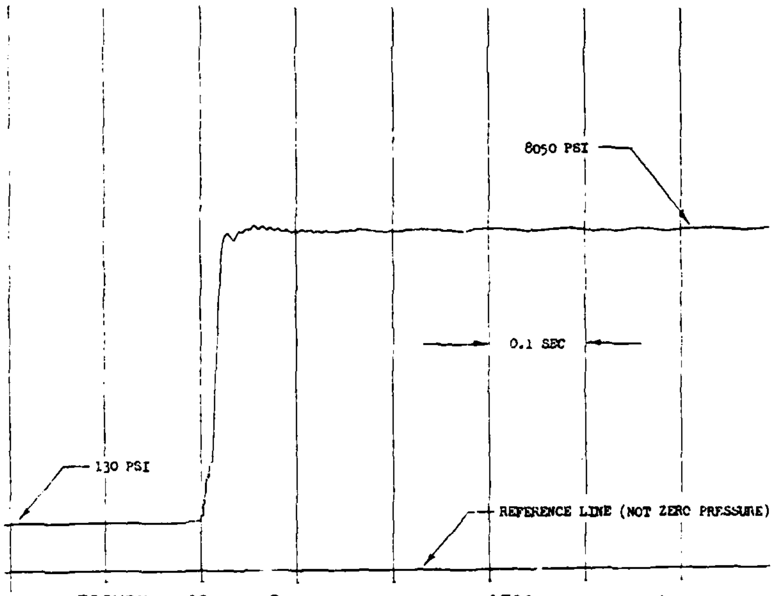


FIGURE 40. Pressure surge at AFCS yaw actuator with restrictor in 3-way valve port 'P'

4.4.3 Tubing Vibration

4.4.3.1 Test Procedure. Simulator tubing vibration was measured to verify that stress levels were satisfactory. Two miniature accelerometers were mounted on a small block that was attached to tubing at selected locations throughout the simulator. One accelerometer sensed vertical motion, the other horizontal motion. A block diagram of the electronic equipment used determine the frequency and 'g' level of vibration peaks is shown on Figure 41. Vibration amplitude was calculated using:

$$A = \frac{19.57\ g}{f^2}$$

where, A = vibration amplitude, inches peak-to-peak

g = acceleration, $ft/sec^2 \div 32.17\ ft/sec^2$

f = vibration frequency, Hz

4.4.3.2 Results. Sixteen locations were surveyed over a pump speed range of 2000 to 6000 rpm. Figure 42. Pump ripple frequency was the primary excitor of tubing vibration (frequency = pump rpm x 9 ÷ 60). Results of the survey are given on Tables 11 and 12.

Determination of maximum allowable tube deflection is summarized on Figure 43. A comparison of measured and maximum acceptable vibration amplitudes is given below.

Tube O.D., inches	Measured Vibration, max. P-P, inches	Acceptable Vibration, max. P-P, inches
3/16	0.0052	.076
1/4	0.0017	.058
3/8	0.0005	.038
1/2	0.0055	.028

Tubing vibration levels observed on the simulator were thus satisfactory. This has been demonstrated by the fact that no tubing/fitting failures occurred during simulator testing that were attributed to excessive vibration.

INSTRUMENTATION

1. HEWLETT-PACKARD M/N 5246L
2. SPECTRAL DYNAMICS M/N SD114B
3. ENDEVCO M/N 2222B
4. ENDEVCO M/N 2731B
5. ENDEVCO M/N 2735
6. UNHOLTZ-DICKIE M/N TF22
7. MOSELEY M/N 2D
8. SPECTRAL DYNAMICS M/N SD103

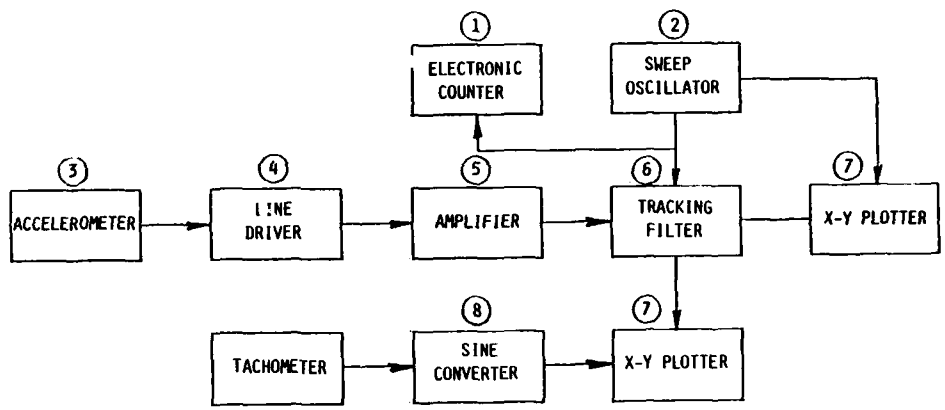


FIGURE 41. Tubing vibration instrumentation

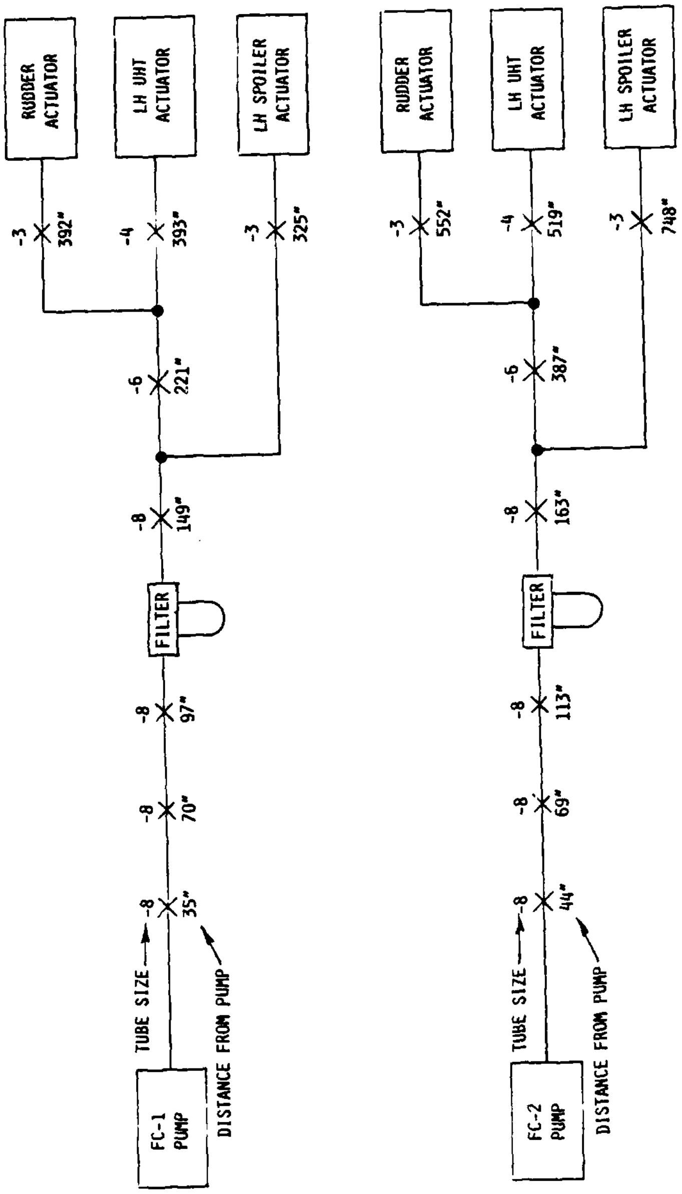


FIGURE 42. Tubing vibration measurement locations

TABLE 11. Tubing vibration survey, FC-1 system

LOCATION	TUBE SIZE	PUMP RPM	VERTICAL VIBRATION	PUMP RPM	HORIZONTAL VIBRATION
35"	-8	4324 5022 5326	.00077 .00054 .00029	3876 4428 5025	.00020 .00095 .00082
70"	-8	2266 4494 5177	.0001 .00097 .00051	2176 4482 5798	.00023 .00093 .00030
97"	-8	2260 4460	.0024 .0014	2241 2972 4441	.0015 .00093 .0035
149"	-8	4580 5512	.00033 .00036	1988 2692	.0023 .00071
221"	-6	3253 4293 5519	.00016 .00012 .00010	2515 4328	.00018 .00027
393"	-4	2257 4514 5098	.00023 (1st H.) .00023 .00022	2255 4508 5484	.0017 (1st H.) .0013 .00010
392"	-3	2296 3426	.00003 (2nd H.) .00002 (1st H.)	2297 3466	.00004 (2nd. H) .00003 (1st. H)
325"	-3	2591 3163 3594	.0023 .0010 .0011	2589 3617 4006	.0015 .0005 .0003

NOTES:
1. All tubing pressurized with 8000 psi
2. Vibration amplitude values are inches peak-to-peak and are maximum values observed.
3. Vibration values are at fundamental frequency except as noted (2nd H. = second harmonic frequency)
4. See Figure 42 for location details

TABLE 12. Tubing vibration survey, FC-2 system

LOCATION	TUBE SIZE	PUMP RPM	VERTICAL VIBRATION	PUMP RPM	HORIZONTAL VIBRATION
44"	-8	2826 5215 5645 5892	.0052 .00048 .0028 .0020	3048 3859 4411	.0010 .00040 .00026
69"	-8	3862 4407 5168	.00022 .00035 .00028	2931 4377	.0055 .00096
113"	-8	2226 2500 4400 5004	.00060 .00071 .0011 .00080	2264 2500 4400 5004	.0031 .00084 .00050 .0016
163"	-8	2162 4369 5693	.0011(1st H.) .0011* .00065	4369 5692	.00015 .00040
387"	-6	2856 5681	.0005 (1st H.) .0008	3452 4349	.00007 (1st H.) .00005 (1st H.)
519"	-4	2055 3042 4499	.00007 (1st H.) .00006 (1st H.) .00003 (1st H.)	2048 3032 4481	.00016 (1st H.) .00003 (1st H.) .00005 (1st H.)
552"	-3	3387 4294	.00003 .00002 (1st H.)	2767 4458	.00005 .00001 (1st H.)
748"	-3	2558 4309	.0001 .0052*	2415 3810	.00003 .00001
*Vibration at 71 Hz					

NOTES:
1. All tubing pressurized with 8000 psi
2. Vibration amplitude values are inches peak-to-peak and are maximum values observed.
3. Vibration values are at fundamental frequency except as noted (2nd H. = second harmonic frequency).
4. See Figure 42 for location details.

Stress Levels

Maximum allowable stress for 3Al-2.5V Ti tubing	33,000 psi
Longitudinal stress in tubing due to 8000 psi hydraulic pressure	20,000 psi
Maximum acceptable bending stress due to tube vibration	13,000 psi

R Factor

$$R = \frac{\text{min. stress}}{\text{max. stress}} \approx +1 \qquad \therefore \text{ No fatigue damage occurs}$$

Assumptions

1. Spacing between tube clamps: 12 in.
2. Deflection Mode: simple beam, uniform load

Tube deflection Producing 13,000 psi Stress

Tube O.D.	Deflection, in.
3/16	0.038
1/4	0.029
3/8	0.019
1/2	0.014

FIGURE 43. Maximum allowable tube deflection

4.4.4 Actuator Frequency Response

4.4.4.1 Test Procedure. Dynamic response of the LH UHT actuator was determined under both load and no-load conditions for three modes of operation.

- o FC-1 and FC-2 systems operating at 8000 psi
- o FC-1 system only operating at 8000 psi
- o FC-2 system only operating at 3000 psi

Actuator input was maintained at a constant sinusoidal amplitude using the AFCS pitch actuator as a driver. Operation was closed loop through mechanical feedback provided by the UHT linkage system. A DC position pot was used to sense displacement of the input push rod. A second DC pot was used to sense UHT actuator piston motion. Input/output data were displayed by a two channel strip chart recorder. Wave form, input/output magnitudes, and phase angle were observed on the recordings. The GSE was used to power the UHT actuator with 3000 psi pressure (see section 4.6). Input fluid temperature was maintained at approximately +140°F for all tests.

4.4.4.2 Results. UHT actuator frequency response is shown on Figures 44 and 45. The data indicates overdamped operating characteristics. There was little difference between response with or without load when cycling at 8000 psi. Performance degraded slightly with operation at 3000 psi.

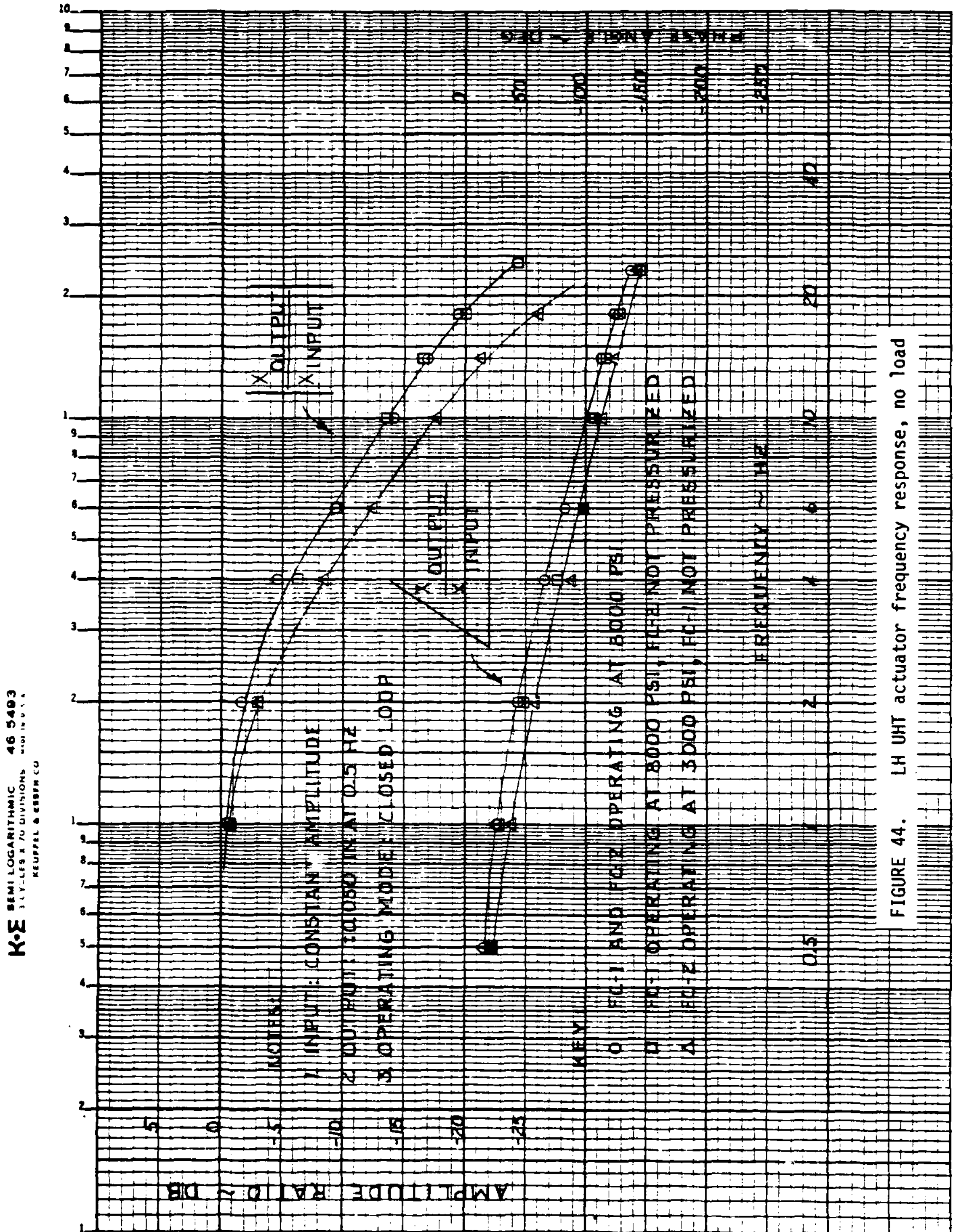


FIGURE 44. LH UHT actuator frequency response, no load

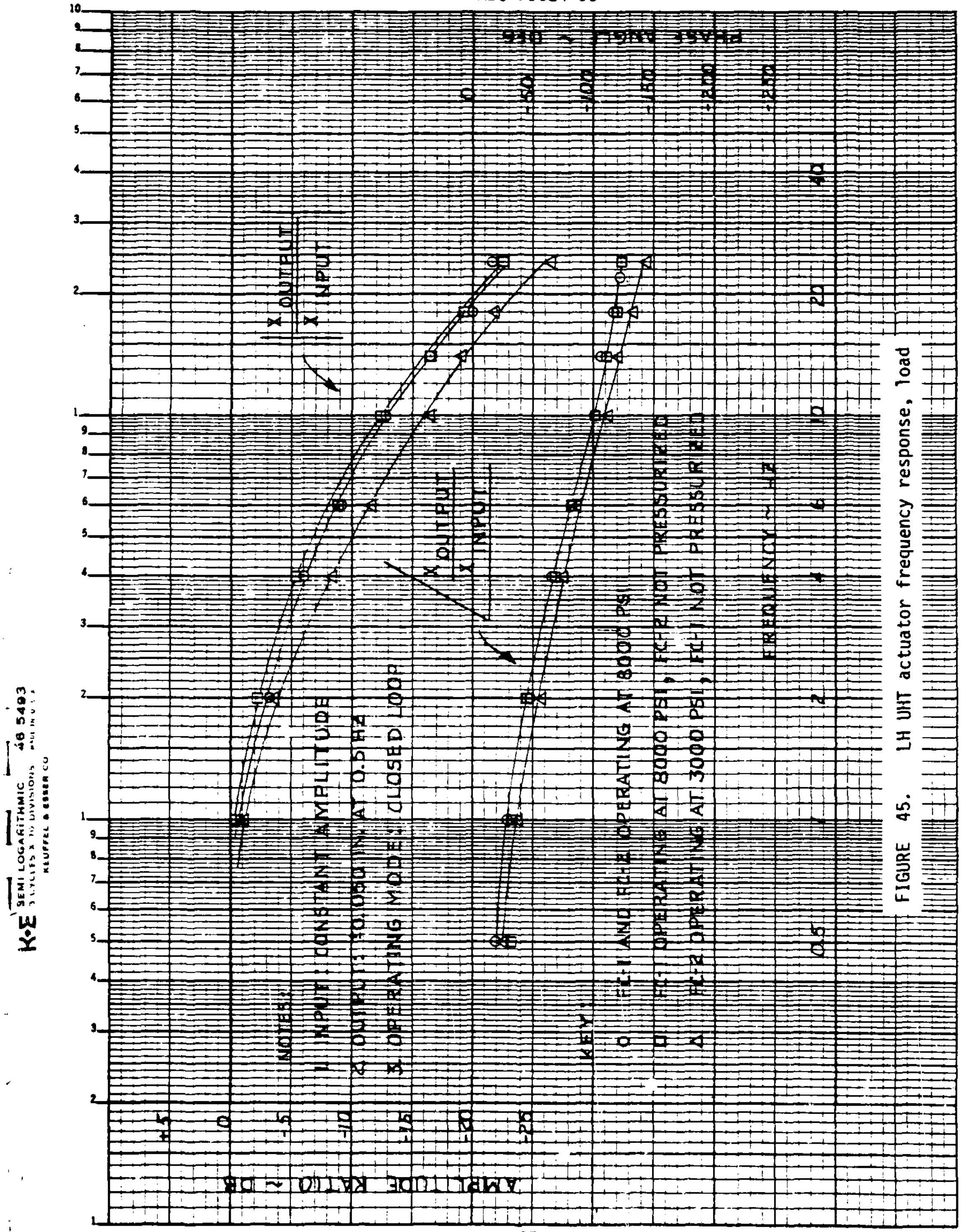


FIGURE 45. LH UHT actuator frequency response, load

AD-A169 884 FABRICATION AND TESTING OF LIGHTWEIGHT HYDRAULIC SYSTEM SIMULATOR HARDWAR..(U) ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AIRCRAFT OP.. W N BICKEL ET AL. 2/4

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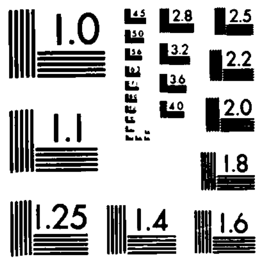

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

4.5 ENDURANCE

This test was conducted to demonstrate that component performance and reliability are satisfactory for long periods of operation. A typical flight mission was simulated and repeated until a total of 600 hours of operation was accumulated. Component performance checks were made at 150 hour intervals. Selected actuators were disassembled at these times and examined for wear.

4.5.1 Cycling Program

Load/stroke magnitude and cycle distribution were based on the MIL-C-5503 schedule shown below:

	No. of Cycles	% of Total
Full stroke & load	50,000	1%
One-half stroke & load	250,000	5%
10% stroke & load	700,000	14%
2% stroke & load	4,000,000	80%
	5,000,000	100%

The cycling program was designed to profile a typical two hour mission: Taxi, Take-off, Cruise, Mission, Cruise, and Landing. The two hours were broken down into 24 five minute steps. The program used for the initial test system is shown on Table 13. Mission/profile cycling used for the final test system was modified to accommodate the seal test fixture and to provide more realistic pump speed conditions, Table 14. All primary flight control actuators, except the spoiler, accumulated cycles as follows:

Load/ Stroke	Cycling Rate	Total Cycles
2%	3 Hz	5400
10%	1 Hz	900
50%	0.25 Hz	375
100%	0.12 Hz	72
		6747/2 hrs.

The LH spoiler operates when the pilot's stick is moved left; the RH spoiler functions when the stick is moved right. A motion limiting bungee used to accomplish this prevented operating the LH spoiler with 2% inputs. Total spoiler cycles were therefore 1347 for each 2 hours of simulator operation.

Secondary flight control actuators were operated at the rate of 1 cpm during two steps in the program. Total cycles accumulated were thus 10 cycles for each 2 hours of simulator operation.

The total number of cycles run was 6747 x 300 = 2,024,100. When Phase I compatibility test cycling, reference 1, is added to this number, some actuators were operated over 3,000,000 cycles.

4.5.2 Test Conditions

4.5.2.1 Temperature. Cycling was conducted at room temperature with fan air circulation to simulate compartment air movement. Pump inlet fluid temperature was maintained in the range of +190 to +210°F. Pump case drain fluid was not allowed to exceed +275°F. Actuator return fluid temperatures ranged from +100 to +240°F depending on location and cycling mode.

4.5.2.2 Hydraulic Fluid. Fluid samples were taken periodically throughout the test to monitor contamination level. Hiac electronic equipment was employed to make particle counts. System health was monitored periodically by means of patches made of debris collected in the pressure, return, and pump case drain filters. Fluid viscosity measurements to check shear stability were not taken because of the frequent need to replenish fluid lost in the contamination checks, patch tests, and actuator disassembly inspections.

4.5.2.3 Pump Inspections. Pump wear in areas such as piston shoes, pintle bearings, and valving surfaces was monitored frequently during the early stages of testing. This was done by making periodic patches of debris taken from the pump case drain filter. After each 50 hours of simulator running time the pump was shipped to the supplier for disassembly and inspection. The pump was then returned to NAAO-Columbus for resumption of mission/profile cycling.

Pintle bearing wear was a particular concern throughout the test. Attempts were made during the course of simulator cycling to improve bearing life by:

- using bearings with specially hardened races
- using slightly larger bearings (as large as the existing pump housing would permit),
- using bearings with crowned rollers.

Installation of significantly larger pintle bearings that require a pump housing re-design has recently been completed. These pumps are scheduled for testing and evaluation during 600 additional hours of simulator operation, reference Section 1.4.

TABLE 13. Mission/profile cycling program, initial test system

STEP NO.	ROLL AILERON/ SPOILER	PITCH, UHT	YAW, RUDDER	AFCS ACTUATORS	SPEED BRAKE, L.E. FLAPS	ACTUATOR LOADING	PUMP RPM
1	0	0	0	Off	Off	Off	3400
2	0	0	0	Off	Off	Off	3400
3	2%	10%	50%	On	Off	Off	3400
4	10%	50%	2%	On	Off	Off	3400
5	50%	2%	10%	On	Off	Off	3400
6	0	0	0	Off	Off	Off	3400
7	50%	2%	10%	On	On	On	5900
8	10%	50%	2%	On	Off	On	5900
9	0	2%	100%	On	Off	On	5900
10	2%	50%	0	On	Off	On	5900
11	100%	0	2%	On	Off	On	5900
12	2%	100%	50%	On	Off	On	5900
13	0	0	0	On	Off	On	5900
14	0	0	0	On	Off	On	5900
15	0	0	0	On	Off	On	5900
16	2%	10%	50%	On	Off	On	5900
17	2%	50%	100%	On	Off	On	5900
18	50%	2%	10%	On	Off	On	5900
19	100%	2%	50%	On	Off	On	5900
20	0	50%	2%	On	Off	On	5900
21	50%	10%	2%	On	Off	On	5900
22	2%	0	50%	On	On	On	5900
23	50%	2%	0%	On	Off	On	5900
24	10%	100%	2%	On	Off	On	5900

TABLE 14. Mission/profile cycling program, final test system

STEP NO.	ROLL AILERON/ SPOILER	PITCH UHT	YAW, RUDDER	SEAL FIXTURE	AFCS ACTUATORS	SPEED BRAKE, L. E. FLAP	ACTUATOR LOADING	PUMP RPM
1	0	0	0	0	Off	Off	Off	3400
2	0	0	0	0	Off	Off	Off	3400
3	2%	10%	50%	S	On	Off	Off	3400
4	10%	50%	2%	S	On	Off	Off	3400
5	50%	2%	10%	S	On	Off	Off	3400
6	0	0	0	0	Off	Off	Off	5900
7	50%	2%	10%	L	On	On	On	5900
8	10%	50%	2%	S	On	Off	On	5900
9	0	2%	100%	0	On	Off	On	5900
10	2%	50%	0	S	On	Off	On	4900
11	100%	0	2%	L	On	Off	On	4900
12	2%	100%	50%	0	On	Off	On	4900
13	2%	2%	2%	S	On	Off	On	5900
14	2%	2%	2%	S	On	Off	On	5900
15	2%	2%	2%	S	On	Off	On	5900
16	0	10%	50%	S	On	Off	On	5400
17	0	50%	100%	0	On	Off	On	5400
18	50%	0	10%	L	On	Off	On	5400
19	100%	0	50%	L	On	Off	On	4400
20	0	50%	0	0	On	Off	On	4400
21	50%	10%	0	L	On	Off	On	4400
22	0	0	50%	S	On	On	On	4400
23	50%	0	0	L	On	Off	On	4400
24	10%	100%	0	S	On	Off	On	4400

NOTE: S = short stroke (±0.10 in.) at 2 Hz

L = long stroke (±1.0 in.) at 0.07 Hz

4.5.2.4 Performance Checks. Component performance tests conducted at 0, 150, 300, 450, and 600 hours of simulator operation were as follows:

Component	Test
Pump(s)	Overall efficiency Heat rejection
Flight control actuators	Null leakage Piston seal leakage Rod seal leakage (accumulation)
Solenoid Valves	Internal leakage
Restrictors	Flow rate
Relief valves	Internal leakage Cracking & re-seat pressures

Pump performance was determined on a test bench. Actuator and solenoid valve leakage checks were run with the component installed in the simulator, but plumbed individually to a portable, 0.5 gpm, 8000 psi industrial hydraulic power supply. This was done to facilitate testing and avoid unnecessary wear on the LHS pumps.

After performance testing was completed, selected flight control actuators were removed from the simulator and disassembled. All dynamic seals and wear surfaces were examined and their condition recorded. Seals with excessive wear were replaced. Photographs were taken of selected parts. The actuators were then re-assembled and re-installed in the simulator.

4.5.2.5 Data Collection. Four types of data logs were maintained to record test information.

- Mission/Profile log sheet
- Performance test results
- Individual component service records
- Daily work log

Examples of each are shown on Figures 46 through 49. Failures and malfunctions, briefly noted on the mission/profile log sheet, were detailed, analyzed, and cataloged in a separate file as illustrated in Figure 50.

DATE	TIME OF DAY	MISSION/STEP	TEMPERATURES FC-1 11 PUMP INLET °F	TEMPERATURES FC-1 12 PUMP CASE °F	TEMPERATURES FC-2 31 PUMP INLET °F	TEMPERATURES FC-2 32 PUMP CASE °F	41 AMBIENT AIR °F	PRESSURES FC-1 PUMP DISCH PSIG	PRESSURES FC-1 PUMP CASE PSIG	PRESSURES FC-2 PUMP DISCH PSIG	PRESSURES FC-2 PUMP CASE PSIG	FLOWS FC-1 1 PUMP INLET HZ	FLOWS FC-1 2 PUMP CASE HZ	FLOWS FC-2 3 PUMP INLET HZ	FLOWS FC-2 4 PUMP CASE HZ	ΔP INDICATOR C P R	PUMP SPEED RPM	TOTAL RUNNING TIME HRS	REMARKS
2-20-85		216/3						8100	123	8100	125	185	183	220	157	✓ ✓ ✓			
	1535	216/5	204	258	168	246	82	8000	123	8000	127	246	227	194	123				
	1540	216/6	193	245	181	238	83	8000	122	8000	127	274	242	80	63		3449	.40	
	1551	216/8	199	250	172	248	83	8000	122	8000	124	256	233	306	240		5956	.47	
2-2 85	0342	216/10	180	221	170	218	78	5050	122	8050	122	241	208	302	226		5837	.65	
	0351	216/12	185	232	177	226	79	8000	118	8000	120	251	216	323	228		4937	.85	
	0356	216/13	203	252	193	248	80	8000	120	8000	125	276	259	185	123		4529	1.02	
	0511	216/16	196	248	194	250	80	8000	127	8000	124	247	249	221	161		5914	1.07	
	0920	216/18	187	251	178	250	82	8000	122	8000	127	289	263	135	79		5419	1.34	
	0947	216/20	173	212	164	210	79	8000	120	8000	120	226	191	292	199		5451	1.50	
	1003	216/23	158	213	145	210	81	8000	122	8000	124	239	205	125	63		4372	1.70	
																	4434	1.95	
2-21-85	1030	217/3	161	198	168	213	81	8000	120	8000	123	194	191	211	149				
	1040	217/5	203	257	154	253	82	8000	123	8000	127	246	233	188	129		3377	.18	
	1045	217/6	191	245	184	241	82	8000	122	8000	125	271	248	81	67		3387	.34	
	1057	217/8	204	256	197	254	82	8000	122	8000	123	255	251	292	241		5946	.43	
	1127	217/10	195	247	197	252	83	8000	123	8000	123	267	247	313	244		5832	.62	
	1117	217/12	190	236	182	233	83	8000	118	8000	120	249	229	318	257		4912	.79	
	1121	217/13	208	258	200	255	84	8000	123	8000	128	262	245	185	123		4939	.95	
	1326	217/16	198	248	194	246	85	8000	122	8000	124	226	210	226	165		5916	1.02	
	1344	217/20	195	241	189	238	87	8000	120	8000	120	245	222	308	229		5430	1.32	REPAIRED RUDDER
	1416	217/23	144	192	137	198	86	8000	127	8000	127	219	203	125	60		4435	1.65	ACTUATOR WITH A NEW
																	4461	1.95	ROD END CLEVIS.
2-21-85	1434	218/3	172	214	179	226	87	8100	123	8000	123	212	195	212	162				
	1443	218/5	203	258	179	257	88	8000	123	8000	127	250	234	185	132		3433	18	
	1449	218/6	194	247	191	247	89	8000	122	8000	124	273	252	82	65		3456	.34	
	1459	218/8	201	251	195	250	89	8000	122	8000	123	230	242	314	247		5921	.42	
	1509	218/10	202	261	198	258	89	8000	122	8000	125	245	261	312	245		5867	.60	
	1522	218/12	200	247	191	243	88	8000	120	8000	120	254	234	320	256		4808	.78	
	1526	218/13	209	263	199	258	89	8000	125	8000	125	260	242	193	124		4897	1.00	
	1342	218/16	210	263	206	263	90	8000	125	8000	127	259	255	238	178		5887	1.05	
	1351	218/18	196	260	188	259	90	8000	125	8000	127	270	256	135	87		5445	1.33	
2-22-85	0916	218/20	165	198	161	198	74	8000	120	8000	120	207	186	255	241				
	0535	218/23	154	208	158	219	72	8000	123	8000	123	226	206	111	84		4416	2.13	

FIGURE 46. Typical mission/profile log

L/H UHT ACTUATOR LEAKAGE HISTORY

150 TEST HOURS

9-19-83 FC-1 NULL LEAKAGE 4.6cc 15sec; 5.5cc 15sec; 5.4cc 15sec; AVG. 20.7cc/MIN — WITH INPUT DITHER – LEAKAGE SILTS UP TO DROPS WITHOUT DITHER

FC-1 PISTON SEAL LEAKAGE ZERO (ACT'R FULL EXT) WAIT 3MIN – MEAS 1MIN

9-19-83 FC-2 NULL LEAKAGE 7.1cc 15sec; 7.1cc 15sec; AVG 28.4cc/MIN — WITH INPUT DITHER

FC-2 PISTON SEAL LEAKAGE TRACE (ACT'R FULL RET'D) WAIT 3MIN – MEAS 1MIN

2-15-84 ROD SEAL LEAKAGE 83 DROPS (200 hr)
3-13-84 ROD SEAL LEAKAGE 71 DROPS (250 hrs)
4-18-84 ROD SEAL LEAKAGE 67 DROPS (300 hrs)
CENTER SEALS 0 DROPS (300 hrs)

300 HOURS CHECK

6-11-84 NULL LEAKAGE FC-1 8.0cc 15sec; 7.2cc 15sec; 6.3cc 15sec; 6.8cc 15sec — WAIT 20sec – MEAS. 15sec MANUAL LIGHT DITHER LEAKAGE SILTS UP AND GOES TO DROPS OTHERWISE

NULL LEAKAGE FC-2 8.5cc 15sec; 5.8cc 15sec; 6.6cc 15sec; 5.8cc 15sec — WAIT 20 sec – MEAS 15sec MANUAL LIGHT DITHER LEAKAGE SILTS UP AND GOES TO DROPS OTHERWISE

PISTON SEAL LEAKAGE FC-1 (TRACE)
FC-2 (TRACE)

2-1-85 ROD SEAL LEAKAGE AFTER FLIGHT PROFILE 225 — 132 DROPS

5-8-85 ROD SEAL LEAKAGE END OF FLIGHT PROFILE 300 — 115 DROPS

FIGURE 47. Typical component performance record

HISTORY FC-1 PUMP MODEL PV3-047-2
P/N 570937
S/N MX346581

DATE	REASON FOR REMOVAL OR RUNNING	OPERATING TIME	TOTAL TIME
JAN 28, 1983	CHECK OUT FC-1 SYSTEM WITH 50% LOAD - CHECK OUT PROGRAMER 3400RPM	2.4	2.4
JAN 31, 1983	CHECK OUT L.E. FLAP LOAD 3400RPM	.75	3.15
FEB 1, 1983	CHECKOUT FLOW METERS 3400RPM	.92	4.07
FEB 2, 1983	CHECKOUT OSCILLOGRAPH 3400RPM	.35	4.42
FEB 3, 1983	CHECKOUT OSCILLOGRAPH 3400RPM	.40	4.82
FEB 4, 1983	CHECKOUT OSCILLOGRAPH 3400RPM	.95	5.77
FEB 7, 1983	STEADY-STATE BASELINE 3400RPM	2.20	7.97
FEB 7, 1983	STEADY-STATE BASELINE 5900RPM	1.3	9.27
FEB 8, 1983	RESONANCE SEARCH 3400RPM → 5900RPM	1.95	11.22
FEB 9, 1983	RESONANCE SEARCH 3400RPM → 5900RPM	.95	12.17
FEB 10, 1983	RESONANCE SEARCH & TRANSIENT 3400RPM → 5900RPM	2.20	14.37
FEB 11, 1983	TRANSIENT SURVEY 3400RPM & 5900RPM	1.70	16.07
FEB 17, 1983	CHECKOUT UHT ACTUATOR 3400RPM	.30	16.37
FEB 18, 1983	CHECKOUT CONTROL SYSTEM 3400RPM	.80	17.17
FEB 18, 1983	REMOVED PUMP FOR PERFORMANCE TEST		
FEB 23, 1983	COMPLETED PUMP PERFORMANCE TEST	2.0	19.17
FEB 28, 1983	CHECKOUT LOAD SYSTEM-RUDDER-OUT 3400RPM	.80	19.97
MAR 1, 1983	CHECKOUT LOAD SYSTEM (COMPLETE) 3400RPM	1.70	21.67
MAR 1, 1983	STARTED TEST-STOP ON END OF CYCLE 21 (STEP)	1.70	23.37
MAR 2, 1983	CHECKOUT SYSTEM 3400RPM	.15	23.52
MAR 2, 1983	COMPLETED FIRST CYCLE STEP 21 TO 24	.35	23.87
APRIL 6, 1983	CHECKOUT ACTUATORS 3400RPM	.50	24.37
APRIL 7, 1983	CHECKOUT ACTUATORS 3400RPM	1.30	25.67
APRIL 7, 1983	SIMULATED FLT RUN #2	2.10	27.77
APRIL 7, 1983	CHECKOUT STICK CONTROLS 3400RPM	.20	27.97
APRIL 8, 1983	SIMULATED FLT 3, 4, & 5	6.10	34.07
APRIL 11, 1983	SIMULATED FLT 6	2.03	36.10
APRIL 11, 1983	CHECKOUT UHT AMPLIFIER 3400RPM	.20	36.30
APRIL 11, 1983	SIMULATED FLT #7	2.05	38.35
APRIL 12, 1983	SIMULATED FLT #8	2.07	40.42
APRIL 13, 1983	SIMULATED FLT #9	2.02	42.44
APRIL 13, 1983	SIMULATED FLT #10	2.10	44.54
APRIL 14, 1983	SIMULATED FLT #11	2.05	46.59
APRIL 14, 1983	SIMULATED FLT #12	2.03	48.62
APRIL 15, 83	SIMULATED FLT # 13 & 14	4.06	52.68

FIGURE 48. Typical component service log

DATE		TASK
3-26-85	1.	RAN SIMULATOR 6 HOURS
3-27-85	1.	TIGHTEN ALL FITTINGS AT L/H UHT ACTUATOR - NO IMPROVEMENT
	2.	REMOVED L/H UHT FROM SIMULATOR
	3.	REMOVED AFT END CAP P/N 83-00214-103
	4.	REPLACE "O" RING P/N MS 27595-225
	5.	REPLACED END CAP
	6.	INSTALLED ACTUATOR IN SIMULATOR - NO IMPROVEMENT
	7.	REMOVED L/H ACTUATOR FROM SIMULATOR
	8.	REMOVED AFT END CAP FROM ACTUATOR FOR INSPECTION
	9.	TOOK PART TO M+P LAB FOR INSPECTION - NO CRACKS FOUND
	10.	TOOK PART TO HEAT TREAT Bldg 3 to MAGNAFLUX PART - SEVERAL CRACKS FOUND
	11.	RAN SIMULATOR 2½ HOURS
3-28-85	1.	RAN PATCH TESTS OF FC-1 + FC-2 CASE DRAIN OIL SAMPLES.
	2.	ADDED HYDRO FLUID TO FC-1 + FC-2 SYSTEM AFTER LOW FLUID AUTO SHUT DOWN OF FC-1 SYSTEM
	3.	SHIPPED 8000 PSI ACTUATOR TO NADC WITH ALL OF THE ELECTRONICS.
	4.	RAN SIMULATOR 4 HOURS 15 MIN.
3-29-85	1.	EQUIPMENT WOULD NOT COME ON - FOUND DEFECTIVE POWER SWITCH
	2.	REMOVED DEFECTIVE SWITCH
	3.	PUT IN NEW POWER SWITCH
	4.	REMOVED R/H UHT FROM SIMULATOR
	5.	REMOVED AFT END CAP FROM ACTUATOR
	6.	INSTALLED AFT END CAP FROM R/H UHT INTO L/H UHT ACTUATOR
	7.	INSTALLED L/H UHT ACTUATOR IN SIMULATOR.
	8.	MADE FOUR OIL RESERVOIRS TO MEASURE OIL LEAKAGE FOR SEAL TEST FIXTURE
	9.	INSTALLED OIL RESERVOIRS
	10	RAN SIMULATOR 2 HOURS 15 MIN.

FIGURE 49. Typical daily work log

LH UHT ACT'R

DATE: 3-27-85

PHASE I + II — PHASE I — II

NO. HOURS: 166 + 464 = 630 NO. CYCLES: 1,055,000 + 1,569,000 = 2,624,000

LOCATION: BASE END SUPPORT P/N 83-00214-101

FAILURE MODE: LEAKAGE AT APPROX. 1 DROP/MIN

REMARKS: — BASE END SUPPORT REMOVED FROM ACTUATOR
— DIAMETRAL SEAL IS OK
— NO CRACKS IN PART COULD BE SEEN
— PART WAS MAGNAFLUXED IN BLDG 3
— 2 CRACKS WERE FOUND IN FILLET AREA AROUND BASE OF TONGUE. ONE CRACK HAD PROPAGATED COMPLETELY THRU THE WEB AREA
— FILLET AREA WAS ROUGH DUE TO TOOLING MARKS. FINISH WAS 125 OR WORSE

— ANALYSIS BY D. TODD DISCLOSED 43,000 PSI OCCURRED AT FULL LOAD. CONSIDERING THE FILLET EFFECT AND THE WORST NOTCH FACTOR, LIFE IS 100,000 CYCLES. PART HAD ≈ 26,000 FULL LOAD CYCLES. (SEE ATTACHED ANALYSIS SHEET)

CAUSE OF FAILURE: UNDER-DESIGN & FATIGUE

REMEDY: — INCREASE WALL THICKNESS BY .12 IN. (SEE ATTACHED DWG.)
— REQUIRE 32 FINISH IN FILLET AREA

— TWO NEW BASE END SUPPORTS TO BE FABRICATED (FOR RH & LH ACT'RS)

FIGURE 50. Typical failure analysis record

4.5.3 Test Results

All pertinent events that occurred during the 600 hours of mission/profile cycling are listed in the Test Log presented in Appendix A. The total time that minor components were subjected to 8000 psi is given on Table 15. Maintenance actions are shown on Table 16. Summaries of component performance are discussed in the following sections.

4.5.3.1 Pumps. Pump operating time totals are listed in Table 17. Performance summaries are given on Table 18. Overall efficiency was generally satisfactory. FC-1 and "spare" pump heat rejection was higher than the design goal of 300 BTU/min; FC-2 pump heat rejection was acceptable. Transient response, stability, pressure ripple, pressure droop, and compensator drift of all pumps was excellent. Pump dynamics were matched well to system impedance.

Pump endurance characteristics were good except for the pintle bearings which were under-designed. Sliding/bearing interface surfaces at the piston shoes/cam, piston/cylinder bores, and valving block exhibited normal wear characteristics. Three different approaches were tried to reduce wear in the pintle bearings (see section 4.5.2). Bearing life was improved but not significantly. Fabrication of pumps with larger pintle bearings and a housing re-design were recently completed (September, 1985). These units, Vickers P/N PV3-047-3, will be used during the second 600 hours of endurance testing to be conducted on the LHS simulator. The re-designed pumps are expected to have lower heat rejection as well as longer life.

4.5.3.2 Actuators. Actuator cycles and cycling time totals are presented in Tables 19 and 20, respectively. The cycle quantities and cycling hours include those accumulated in Phase I, reference 11, and tests conducted by Vought in Phase II. Four actuators have completed approximately 3,000,000 cycles: LH UHT, rudder, yaw AFCS, and aileron. No major difficulties were encountered with any actuator other than minor problems related to quality control during initial fabrication and typical maintenance actions.* One fatigue failure occurred as a result of under-design which was corrected. The endurance characteristics of all actuators were considered satisfactory, and further cycling is planned to accumulate an additional 2,000,000 cycles.

Piston and rod seal leakage summaries are given on Table 21. Maximum allowable rod seal leakage is 1 drop/25 cycles, reference MIL-C-5503. All piston and rod seal leakage was satisfactory. Rod seal maintenance actions are shown on Table 16.

* FC-1 and FC-2 cylinder bores in the aileron actuator were damaged in a prior test by piston seals containing steel back-up rings. The cylinders were honed in an effort to eliminate bore scoring. Only FC-2 bore could be repaired. FC-1 section of the aileron actuator was therefore inoperative throughout the 600 hours of simulator testing. A new aileron actuator body is being procured. As a result of this seal problem, all actuators with steel back-up rings in the piston seals were disassembled, the seals removed, and new seals installed. See Appendix 'C' for the piston seals tested, and Table 20 for cycling time accumulated on these seals.

TABLE 15. Total time minor components subjected to 8000 psi

DESCRIPTION	PART NO.	SYSTEM/LOCATION	TIME, HRS.
Accumulator	3321471	FC-2 Power Module	450
Check Valve	P4-858	FC-1 Pump	261
Check Valve	95201-5	FC-2 Pump	750
Check Valve	95200-5	FC-1 Power Module	766
Check Valve	95202-5	FC-2 Power Module	450
Check Valve	P2-858	FC-2 Press. Regulator	450+ Pressure Surge Test
Check Valve	P9-858	FC-1 Run-around	600
Check Valve	P9-858	FC-2 Run-around	300
Check Valve	P11-858	FC-1 Speed Brake	766
Check Valve	P8-858	LH&RH UHT Actuator	300
Check Valve	P1-858	Rudder Actuator	300
Check Valve	P1-858	FC-1 Speed Brake	600
Check Valve	P10-858	FC-1 Speed Brake	600
Filter	AD-A640-83Y1	FC-1 Power Module	766
Filter	AD-A640-83Y1	FC-2 Power Module	450
Hose	F37404008-0300	FC-1 Pump	766
Hose	F37404008-0300	FC-2 Pump	450
Hose	DE6964-3-0282	FC-2, Aileron actuator	600
Hose	28404003-0214	FC-1&2, Spoiler & RFI	107
Manifold	8696-581002	FC-1 Power Module	766
Manifold	8696-581201	FC-1 Power Module	600
Pressure Gage	1218-63-1	FC-2 Power Module	450
Pressure Snubber	95239	FC-1 Power Module	766
Pressure Snubber	95239	FC-2 Power Module	450

TABLE 15. (continued)

DESCRIPTION	PART NO.	SYSTEM/LOCATION	TIME, HRS.
Pressure Transmitter	18-2143	FC-1 Power Module	766
Pressure Transmitter	18-2143	FC-2 Power Module	450
Quick Disconnect	AE80943H	FC-1 Pump Hose	766
Quick Disconnect	AE81214H	FC-1 Pump Port	766
Quick Disconnect	AE81215H	FC-1 Ground Service	766
Quick Disconnect	AE80943H	FC-2 Pump Hose	450
Quick Disconnect	AE81214H	FC-2 Pump Port	450
Quick Disconnect	AE81215H	FC-2 Ground Service	450
Relief Valve	1257A	FC-1 Power Module	766
Relief Valve	1258	FC-2 Power Module	450
Restrictor	REFX0380250AB	FC-1 Speed Brake	58
Restrictor	95461-2	FC-2 L.E. Flap	2
Restrictor	95462	FC-2 L.E. Flap	2
Restrictor	95461-1	FC-2 L.E. Flap	2
Solenoid Valve	3221472	FC-1 Speed Brake	766
Solenoid Valve	3321473	AFCS Pitch Actuator	450
Solenoid Valve	305100	FC-2 Power Module	300
Solenoid Valve	306700	FC-1 AFCS Yaw Actuator	150
Solenoid Valve	306750	FC-2 L.E. Flap	300
Swivel	L38910	FC-1 Speed Brake	58
Swivel	L39010	FC-1 Speed Brake	58
Tubing, Coil	83-00287-1	FC-1P, Spoiler	112 (leaking)
Tubing, Coil	83-00287-3	FC-1R, Spoiler	170 (removed)
Tubing, Coil	83-00288-1	FC-2P, Spoiler	150 (leaking)
Tubing, Coil	83-00288-3	FC-2R, Spoiler	84 (failed)
Tubing, Coil	83-00283-1	FC-1P, RFI	310 (leaking)
Tubing, Coil	83-00283-3	FC-1R, RFI	310 (removed)
Tubing, Coil	83-00284-1	FC-2P, RFI	452 (leaking)
Tubing, Coil	83-00284-3	FC-2R, RFI	452 (removed)

NOTE: Total test time includes Phase I.

TABLE 16. Maintenance action totals

	LOW PRESSURE COMPONENT	8000 PSI COMPONENT
ACTUATORS		
Fixes (rework out-of-tolerance parts)		6
* Worn rod seals replaced (2nd stage O-ring)		16
Worn piston seals replaced		2
Fatigue failure		1
PUMPS		
Removal (excessive wear)		2
MINOR COMPONENTS		
Leaking	2	3
Malfunction	2	2
Fatigue failure		1
BOSS SEAL LEAKS	2	6
COIL TUBING/FITTING LEAKS/FAILURES	1	6
HOSE LEAKS		1
FILTER ELEMENTS REPLACED	8	1
LOAD MODULE		
Mechanical malfunction	1	
Excessive wear	1	
Fatigue Failure	2	—
TOTALS	19	47

*SIMULATOR OPERATING TIME, HR.

ACTUATOR	FC-1 ROD	FC-1 C/D	FC-2 C/D	FC-2 ROD
LH/UHT		150	150	2
Rudder	2 150	150	150	2 150 300
RFI		150	150	
Spoiler/Deflector		150	150	
Aileron			150 300	

NOTES: 1. Selected seals were removed at 150 hours as a general maintenance action. The seals were worn by nibbling, pinching, and abrasion, but none leaked or had a permanent set.

2. Seals replaced at 300 hours had considerable wear but were still operational.

3. The rudder actuator FC-2 rod seal has no rod scraper Use of a scraper is recommended for this application.

TABLE 17. Pump operating time

VICKERS MODEL PV3-047-1, -2

Serial No.	Phase I	Phase II	Vickers Tests	Total
FC-1 346581	158.5	684.7	200	1043.2
FC-2 348168	130.2	212.5	200	542.7
SPARE 346580	.3	220.4		220.7

NOTE: HOURS ARE ACCUMULATED TIME AND INCLUDE:

- Simulator mission/profile cycling
- Simulator check-outs
- Simulator tests
- Pump performance tests
- Simulator demonstrations

TABLE 18. Pump performance checks

SIMULATOR RUNNING TIME, HRS →	0	50	100	150	200	250	340	450	600
FC-1 Pump (S/N 346581)					* reworked	* reworked	* reworked		
Heat Rejection, BTU/MIN	367	354	353	359	362	350	354	345	342
Overall Efficiency, %	85.6	84.0	83.7	83.3	86.7	86.3	82.2	82.5	83.9
Case Flow, GPM	1.30	1.26	1.21	1.27	1.29	1.26	1.33	1.34	1.27
FC-2 Pump (S/N 348168)									
Heat Rejection, BTU/MIN		314					273		293
Overall Efficiency, %		83.0					87.4		88.0
Case Flow, GPM		0.96					.99		1.08
Spare Pump (S/N 346580)							* reworked		
Heat Rejection, BTU/MIN		374					350	335	
Overall Efficiency, %		81.7					82.9	86.2	
Case Flow, GPM		1.42					1.31	1.40	

* Pintle bearings changed

TABLE 19. Actuator cycle totals

ACTUATOR	SIMULATOR RUNNING TIME, HR.				
	0	150	300	450	600
L/H UHT	1,054,800*	1,560,800	2,066,800	2,525,600	3,018,200
R/H UHT	--	--	0	357,100	667,400
Rudder	1,054,800*	1,554,100	2,060,100	2,532,400	3,038,400
Yaw AFCS	1,054,800*	1,560,800	2,066,800	2,572,800	3,078,900
RFI	27,400**	533,400	1,039,400	1,545,400	2,051,500
Spoiler	50,000**	151,000	252,000	353,000	454,100
Aileron	1,054,800*	1,466,400	1,972,400	2,477,900	2,984,400
L.E. Flap	0	750	1,500	2,250	3,000
Speed Brake	4,000*	4,750	5,500	6,250	7,000
Seal Test Fixtures					
FC-1	--	--	0	510,750	1,021,500
FC-2	--	--	--	0	510,750

* CYCLES ACCUMULATED IN PHASE I

** TESTS CONDUCTED BY VOUGHT IN PHASE II

TABLE 20. Actuator seal cycling time totals

ACTUATOR	FC-1			FC-2		
	ROD	PISTON	C/D	C/D	PISTON	ROD
L/H UHT	N.A.	598	766 450	766 450	598	766 598
R/H UHT	N.A.	300	300 300	300 300	300	300 300
Rudder	766 450	598	766 450	766 450	598	766 300
AFCS	766	450	766			
RFI	600 600	450	600 450	600 450	450	600 600
Spoiler	600 600	450	600 450	600 450	450	600 600
Aileron	--	--	--	766 300	570	766 736

NOTES:

1. Time values are hours.
2. Times include Phase I hours.
3. Center dam (C/D) and rod seals are 2-stage (except AFCS). Upper value is 1st stage; lower value is 2nd stage O-ring.

TABLE 21. Dynamic seal leakage summary

ACTUATOR	NO. CYCLES/ 150 HRS.	MAX. ALLOWABLE LEAKAGE/150 HRS.	SYSTEM/ SEAL	SIMULATOR RUNNING TIME, HR. 150	300	450	600
L/H UHT	506,000	20,000	FC-2 Rod	220	221	132	115
			FC-1 Piston	0	T	T	T
			FC-2 Piston	T	T	T	T
R/H UHT	506,000	20,000	FC-2 Rod	---	---	82	111
			FC-1 Piston	---	T	ID	ID
			FC-2 Piston	---	T	T	T
Rudder	506,000	20,000	FC-2 Rod	41	3	0	7
			FC-1 Piston	T	T	T	T
			FC-2 Piston	T	T	T	T
Yaw AFCS	506,000	20,000	FC-1 Rod	28	(1)	(1)	(1)
			FC-1 Piston	(2)	(2)	(2)	(2)
RFI	506,000	20,000	FC-2 Rod	45	0	0	0
			FC-1 Piston	(2)	---	---	---
			FC-2 Piston	(2)	---	---	---
Spoiler	101,000	4,000	FC-2 Rod	(3)	10	10	27
			FC-1 Piston	T	T	T	T
			FC-2 Piston	T	T	T	T
Aileron	506,000	20,000	FC-2 Rod	272	434	242	367
			FC-2 Piston	T	ID	T	T
L.E. Flap	750	30	FC-2 Rod	75	12	34	(4)
			FC-2 Piston	T	T	T	T
Speed Brake	750	30	FC-1 Rod	1	0	0	0
			FC-1 Piston	T	T	T	T

NOTES: 1. Rod seal leakage values are number of drops accumulated in 150 hours

2. Maximum allowable rod seal leakage is 1 drop/25 cycles (Ref MIL-C-5503)

3. Piston seal leakage values are:
T = Trace (less than one drop/min)
D = Drops/min

(1) Not meaningful because of servo valve face seal seepage

(2) Not measured because all cylinder porting is internal

(3) Not meaningful because of coil tube failure

(4) Not meaningful because of coil tube fitting leakage

Actuator control valve null leakage summaries are shown on Table 22. The maximum allowable leakage goal was 125 cc/min. All leakage was satisfactory at the beginning of cycling and trended upward as test time accumulated. At 600 hours, the yaw AFCS and RFI actuators had higher than desired leakage. AFCS actuator leakage occurred primarily in the direct drive 8000 psi electrohydraulic servo valve.

The spoiler/deflector and RFI actuators have shrink-fit control valves -- the valve sleeve has no diametral seals. (All other actuator control valves on the simulator have diametral seals on the sleeve O.D.) The shrink-fit sleeve/housing interface was believed to be leaking in the RFI and spoiler actuators. This was determined by checking valve internal leakage with hard-over inputs. Leakage that occurs with hard-over inputs is normally less than leakage that occurs at null. Although the test data, Table 23, were inconsistent, comparison with null leakage values on Table 22 indicates some sleeve leakage occurred during certain operating modes. Additional study of this condition is warranted.

4.5.3.3 Solenoid Valves. A summary of internal leakage measured at 150 hour intervals is given on Table 24. The maximum allowable internal leakage goal was 10 cc/min. Four valves met this goal; the 4-way speed brake valve did not.

Undetected failures were found during the 450 hour check on valves P/N 3321472 and P/N 3321473, reference Table 2. The cause was attributed to backup ring extrusion that permitted an O-ring to fail. Backup ring material was virgin Teflon; filled Teflon is recommended. Other than the noted discrepancies, the performance of all valves was considered satisfactory.

4.5.3.4 Relief Valves. Relief valve performance is summarized on Table 25. All performance characteristics were satisfactory. No malfunctions or failures occurred.

4.5.3.5 Restrictors. Restrictor performance is shown on Table 26. A slight upward trending of flow occurred as simulator time accumulated. All performance was considered satisfactory.

4.5.3.6 System Filters. FC-1 and FC-2 power modules each contain three filters: pressure line (-8 size), return line (-8 size), and pump case drain (-6 size). All filters contained elements with 5 micron absolute ratings. The fluid cleaniness level goal was NAS 1638, Class 8 or better, reference Table 28. Element replacments during the 600 hour test are shown on Table 27. Because of the special treatment given FC-1 pump during the first 300 hours, see section 4.5.2, the case drain filter element was changed more frequently than would normally be required. On two occassions 15u case drain elements were installed to provide a comparison with 5u element performance. Element replacement intervals apeared to be normal (>300 hr) for the 5u pressure and return line filters.

TABLE 22. Control valve null leakage summary

ACTUATOR	SYSTEM	SIMULATOR RUNNING TIME, HR. 0	150	300	450	600
L/H UHT	FC-1	49	21	28	63	66
	FC-2	22	28	27	41	53
R/H UHT	FC-1	---	---	39	55	75
	FC-2	---	---	25	41	58
Rudder	FC-1	4	5	21	32	35
	FC-2	6	8	17	35	53
Yaw AFCS	FC-1	110	112	132	148	161

RFI	*FC-1	48	21	80	50	70
	*FC-2	68	65	116	126	149
Spoiler	*FC-1	25	24	65	124	97
	*FC-2	22	18	41	52	47
Aileron	---	---	---			
	FC-2	---	26	23	41	24

NOTES:
1. Leakage values are in cc/min
2. Inlet fluid temperature approximately +130°F
3. Maximum allowable leakage: 125 cc/min (goal)

*Some of this leakage may be around shrink-fit control valve (sleeve O.D. has no seals).

TABLE 23. Spoiler/deflector and RFI actuator internal leakage

Simulator Running Time, Hours →			300	450	600
Actuator	System	Direction			
Spoiler/deflector	FC-1	extend	38	42	57
		retract	46	100	79
	FC-2	extend	29	120	49
		retract	44	86	92
RFI	FC-1	extend	144	95	61
		retract	184	159	198
	FC-2	extend	100	122	111
		retract	76	124	113

NOTES: 1. Leakage values are cc/min
2. Valve inputs are hard-over

TABLE 24. Solenoid valve internal leakage summary

VALVE	MODE	SIMULATOR RUNNING TIME, HR. 0	150	300	450	600
Yaw AFCS (3-way) (P/N 3321473)	on off	4 8	4 7	4 7	1500(6)* 8(9)*	4** 8**
Yaw AFCS (3-way) (P/N 306750-1001)	on off	-- --	--- ---	--- ---	T*** T	0 30
Speed Brake (4-way) (P/N 3321472)	on(ext.) on(hold) off(ret.)	28 13 34	30 10 34	43 11 50	1600(52)* 18(17)* 44(60)*	32 12 36
L.E. Flap (4-way) (P/N 306700)	on(ext.) on(ret.) off--	0 T T	T T T	T T T	T T T	T T T
FC-2 Reservoir (2-way) (P/N 305100)	off	--	---	120	40	90

NOTES:

1. Leakage values are cc/min at 8000 psi except:
   T = Trace (less than one drop/min)
   D = Drops/min
2. Inlet fluid temperature approximately +100°F
3. Maximum allowable leakage goal: 10 cc/min

* *Leakage after installation of new seal.*

** Used at 8000 psi for 450 hours; used at 2300 psi for 150 hours.

*** Valve P/N 306750-1001 installed in FC-1 system. Valve P/N 3321473 installed in load system.

TABLE 25. Relief valve performance summary

VALVE	SIMULATOR HOURS	CRACKING PRESSURE, PSI	RESEAT PRESSURE, PSI	INTERNAL LEAKAGE
FC-1 (M/N 1257A)	150	8900	8400	1 drop/min
	600	8900	8400	zero
FC-2 (M/N 1258)	600	8750	8450	zero

TABLE 26. Restrictor performance summary

RESTRICTOR	SIMULATOR RUNNING TIME, HR. 0	150	600
Speed Brake (ext.) (P/N REFX0380250AB) (ret.)	4.0 4.17	4.02 4.18	4.02 4.21
L. E. Flap, Inbrd., 1-way (P/N 95461-1)	1.18	1.18	1.24
L.E. Flap, Inbrd., 2-way (P/N 95462)	1.27	1.24	1.33
L.E. Flap, Outbrd., 1-way (P/N 95461-2)	2.22	2.21	2.28
L.E. Flap, Outbrd., 2-way (P/N 95462)	1.18	1.18	1.23

NOTE: *Flow in gpm at return pressure.*

TABLE 27. Filter element replacement

RUNNING TIME, HRS.	PUMP CASE DRAIN		PRESSURE		RETURN	
	FC-1	FC-2	FC-1	FC-2	FC-1	FC-2
0	5u[1]		5u[1]		5u[1]	
78	5u[2]					
100	5u[3]					
150	15u[4]					
200					5u[4]	
250	5u[3]		5u[3]			
300		5u[1]		5u[1]		5u[1]
342		5u[2]				
460	15u[5]	15u[5]				
560						5u[2]
600						

[1] New test

[2] Filter ΔP button operated

[3] New start with re-worked pump

[4] Plumbing or setup change

[5] Element dirty

The 5u case drain element replacement interval varied from 42 to 210 hours. Use of 15u elements lengthened the replacement interval. Use of a larger flow capacity 5 micron element would also extend the replacement interval.

Although flows in 8000 psi systems are lower than in equivalent 3000 psi systems, maximum flow rates for a given tube size are larger in 8000 psi systems because of higher allowable fluid velocities. For example, a -8 size 3000 psi filter is rated for 6 gpm, while a -8 size 8000 psi filter is rated for 10 gpm. The dirt holding capacity of 8000 psi filters must therefore be larger than 3000 psi filters (for the same tube size) to maintain equal filter element replacement intervals.

4.5.3.7 Fluid Contamination. Hydraulic fluid was drawn periodically from a sampling valve located upstream of the return filter in each power module. A sample consisted of approximately 200 cc of fluid collected in a specially cleaned jar. Particulate contamination was measured with a Hiac M/N PC320 counter and CMB150 sensor during the first 300 hours of simulator cycling. A Hiac M/N 4100 counter and HR300 sensor were used during the second 300 hours. Results of the contamination checks are given on Table 28.

The accuracy of the results were questioned during the second 300 hours of cycling when readings in the 5 to 15u range became large. The sensor was suspected of counting microscopic air bubbles. Eight fluid samples were taken at the 600 hour point to provide a means to verify count accuracy. Four samples were given to Pall Corporation for particulate counts and four jars were stored in the LHS laboratory pending resolution of the contamination measurement equipment problem. Results of the Pall counts and final Rockwell determinations for the 600 hour point are shown on Table 28. Fluid cleanliness was considered satisfactory.

Patch tests were run periodically to examine debris collected in the pressure, return, and pump case drain filters and thus monitor system health. The filter element outer surface was flushed off and debris in the filter bowl was flushed out. All effluent was collected and passed through a 0.45 micron filter patch. The concentrated debris was then examined under a microscope. A black residue was observed on all patches. Metallic wear particles and seal fragments were also present. The black residue has been observed in prior LHS programs and in systems operating at 3000 psi. The residue apparently has no detrimental effect except for filter element replacement. An investigation was conducted by Pall Corporation to identify the composition and source of the black residue. A full report is forthcoming; a brief summary of the analysis is given in Appendix H. The residue is mostly agglomerates of inorganic particles imbedded in relatively larger organic particles. Organic black particles were most numerous. Aluminum, iron, and chromium wear debris all contributed to the black appearance of the particles. Case drain filters had a predominance of iron containing particles, while return line filters held a large number of chromium containing particles. Particle generation was believed to be the result of normal wear on the pump, actuators, seals, and hydraulic fluid and is not unique to 8000 psi systems.

TABLE 28. Fluid contamination

HOURS	SYSTEM	PARTICLE SIZE RANGE, MICRONS					
		1-5	5-15	15-25	25-50	50-100	100+
0	FC-1		1207	39	7	0	0
50	FC-1		16434	1298	182	20	2
64	FC-1		23944	1309	375	82	2
100	FC-1		9416	752	160	20	0
150	FC-1		1059	44	183	25	0
200	FC-1		12463	89	31	0	0
250	FC-1		3825	716	414	127	11
300	FC-1		394	69	19	2	1
490	FC-1		75810	206	92	20	0
490	FC-2		33788	24	10	4	0
542	FC-1		113532	17185	3493	257	2
542	FC-2		33983	1703	466	62	7
*600	FC-1		1984	353	109	32	2
*600	FC-2		1298	597	143	16	6
**600	FC-1	45	20	7	3	2	1
**600	FC-2	45	26	13	3	1	0.4

Reference Standard

NAS 1638, Class 8		64000	11400	2025	360	64

*Manual count made by Rockwell-Columbus.

**Manual count made by Pall Corporation. See Appendix H.

REMARKS

The Rockwell Metrology Laboratory upgraded its fluid contamination measuring equipment during the period when the simulator was being converted from a one system to a two system configuration. New microcomputer based particle counters were procured. This equipment was used to obtain the data at 490 and 542 hours. The accuracy of these particle counts were questioned (see Section 4.5.3.7).

The new Hiac HR300 particle sensors were subsequently found to be more susceptible to foreign liquid contamination than the previously used CMB150 sensors. Water contamination over 100 parts per million (ppm) will cause the HR300 to give erroneous counts. (One drop of water in a 200 cc fluid sample jar is equivalent to 150 ppm.) The water content in the fluid samples taken at 600 hours was 132 ppm (ref. Appendix H).

Particle counts made on the 600 hour fluid samples using the HR300 sensor resulted in numbers over 100,000 in the 5-15μ range. Manual counts of patches made from the same fluid produced satisfactory information. This data is given in Table 28. The disparity between the Rockwell-Columbus and Pall Corporation manual counts was not resolved, but is attributed, at least in part, to differences in techniques and procedures.

4.5.3.8 Fittings. Three types of hydraulic fittings were used at 8000 psi:

Name	Manufacturer	Attachment Method
Dynatube	Resistoflex	Internal swage
Permaswage	Deutsch	External swage
Cryofit	Raychem	Heat shrink

Few problems occurred during the 600 hour test that were related to fittings (except for the coil tubes, see section 4.5.3.10). No fitting failures occurred and only seepage was observed at a few fittings after prolonged operation at 8000 psi. Nearly all of this seepage occurred at the tubing/fitting joint of -3 size Permaswage fittings. Negligible seepage occurred with -4, -6, and -8 tube sizes using Dynatube, Permaswage, or Cryofit fittings. The low pump ripple and resulting low tube vibration levels contributed to the successful fitting results.

Vibration levels occurring in aircraft plumbing installations will be more severe than those experienced on the LHS simulator. For this reason, it is recommended that flex stress/pressure impluse tests be conducted on various tubing/fitting combinations to more fully demonstrate 8000 psi tubing/fitting integrity.

4.5.3.9 Hoses. The pump hoses were -8 size. Two types were evaluated: 1) hose with Kevlar reinforcement braid fabricated by Aeroquip; and 2) hose with steel reinforced braid manufactured by Titeflex. The Aeroquip hose developed a leak in the fitting swage area after 62 hours of operation. Performance of the Titeflex hose was satisfactory after 766 hours of use (Phase I + Phase II).

The aileron hoses were -3 size, made with Kevlar reinforcement braid, and fabricated by Aeroquip. Fluid seeped through the hose wall wetting the outer surface. Although this condition was a concern, no hose failures occurred. The seepage would not be acceptable in an aircraft installation.

Kevlar -3 size hoses were used on a temporary basis to replace coil tubes that failed on the simulator. These hoses, made by Titeflex, were necessarily subjected to severe flexing in the spoiler/deflector installation and moderate flexing at the RFI actuator. Fluid seepage through the hose wall was significant in the spoiler/deflector application, but no failures occurred. Fluid seepage at the RFI installation was negligible.

Performance deficiencies encountered with Kevlar braid hoses indicate that further development effort is required.

4.5.3.10 Coil Tubing. The A-7 spoiler/deflector and RFI installations employ hydraulic extension units with end swivels as flexible connections to transmit hydraulic power to the actuators. These 3000 psi units have a history of leaking. The extension units were replaced with coil tubes on the LHS simulator, Figures 13 and 19. Coil tube fittings attached to the spoiler/deflector actuator had the following motion:

inboard/outboard	1.8 in
fore and aft	0.5 in
up and down	0.5 in

Space available for spoiler/deflector actuator plumbing was severely restricted. The RFI actuator installation was not as severe, either motion-wise or space-wise. Space constraints prevented having a sufficient number of coils to moderate coil tube stress levels in the spoiler/deflector installation. Space available at the RFI actuator permitted more coils to be used and tube stress levels were acceptable. All coil tubes in the spoiler/deflector installation either failed or developed serious leaks early in the program. No RFI actuator coils failed, but some fittings leaked (see Appendix A).

The spoiler tube failures were attributed to two factors: 1) high stress levels in the tubing and 2) an inadequate swage joint between the tube and fitting. The tubing was 3/16 x .035 titanium; the fittings were Deutsch P/N D11200TE-03. The failures were the result of fatigue cracks developing in the tube in the fitting swage area. This fitting/coil tube combination was considered to be an unsatisfactory design.

Failed or leaking coil tubes were replaced with either hoses or Rockwell design coil tubes, Figure 64. The hoses and Rockwell tubes were used to permit continued cycling of the spoiler/deflector and RFI actuators, and were intended as a temporary fix only. The Rockwell tubes were fabricated from 3/16 x .020 21-6-9 CRES or 3Al - 2.5V titanium and had internally swaged fittings.

The A-7E spoiler/deflector installation is not a suitable application for coil tubes because 1) the severe space contraints prevent attaining a satisfactory design, and 2) coil tubes should not be exposed to outside air flow which occurs in this installation. Further development effort is required to provide suitable flexible connections for this unique application.

Torsional coil tubes were used on the L.E. flap actuators. These also employ 3/16 x .035 titanium tubing and Deutsch P/N D11200TE-03 fittings. Performance of these tubes was satisfactory for 2,740 cycles at which time leakage began to occur. The leaky fittings were re-swaged; the leakage stopped. A total of 3,000 cycles were completed at the 600 hour point.

Coil tubing has important potential use in 8000 psi hydraulic systems. Rockwell has addressed coil tube problems encountered during LHS simulator testing and is endeavoring to solve them. Factors affecting coil tube design have been studied and computer programs developed. Work in this area is currently on-going, and results of the study will be documented in the addendum to this report (see section 1.4).

4.6 GROUND SUPPORT EQUIPMENT

An existing 3000 psi AHT-63 portable test stand was modified to operate at 8000 psi. The modification involved: 1) general rehabilitation and 2) replacement of 3000 psi components in the pressure system with 8000 psi components. The ground support equipment is shown on Figure 28; design features are given on Table 1.

The 8000 psi pump in the ground cart was built by Denison Division of Abex Corporation and is a modified version of their P6V Gold Cup series 6000 psi pump. The unit is an axial piston variable volume design with manual servo controls for both displacement and pressure compensation. The pump runs at 1200 rpm, has a 10% overpressure capability, and delivers up to 8 gpm. An integral auxiliary pump provides servo pressure and cooling flow. Separate pumps are used to supply suction boost pressure and to drive the heat exchanger fan.

The GSE was operated a total of 13.0 hours at pressures from 1000 to 9000 psi during the course of conducting:

- o Initial startup, check-outs, and adjustments
- o GSE temperature stabilization determinations
- o Simulator demonstrations by powering FC-1 system
- o Actuator frequency response tests by powering FC-2 system.

Test stand performance was considered good except heat dissipation capacity was marginal. Pump inlet fluid temperatures reached +180°F after 15 minutes of operating FC-1 system. The GSE heat exchanger is rated for 50,900 BTU/hr removal with 20 gpm oil flow. Ground cart tare flows are:

Main pump case leakage	4 gpm @ 8000 psi
Boost pressure pump	17 gpm @ 60 psi
Fan drive pump	6 gpm @ 200 psi
Main pump servo/cooling pump	5.6 gpm @ 500 psi

Tests are planned to determine the heat removal rate necessary to permit continuous operation of the GSE with pump inlet fluid temperature stabilized below 180°F. It should be noted that the 8 gpm main pump design was adapted from a model originally sized to deliver 20 gpm for an 8000 psi stationary test bench. Case leakage remains relatively constant regardless of discharge flow. This causes overall efficiency to be low. Use of a smaller pump (designed to deliver 8 gpm) would reduce heat rejection and heat dissipation requirements.

5.0 MATH MODEL

5.1 INTRODUCTION

Hydraulic system dynamic analysis computer programs developed for the Air Force were implemented initially during Phase I, reference 11. Use of these programs were extended to the full scale LHS simulator in Phase II. Two programs were evaluated:

1. Hydraulic System Frequency Response (HSFR)

   This program predicts locations, amplitudes, and frequencies of standing wave oscillating flows and pressures resulting from the operation of piston type pumps.

2. Hydraulic System Transient Analysis (HYTRAN)

   This program simulates the dynamic response of a hydraulic system to sudden changes in load flow demand, and predicts the pressure and flow disturbances that propagate through the system.

Reference 15 contains background and user information necessary to implement the programs.

5.2 HYDRAULIC FREQUENCY RESPONSE ANALYSIS

5.2.1 Background

Aircraft piston-type pumps cause pressure and flow oscillations (commonly known as pump ripple or pulsations) to be superimposed upon the pressurized hydraulic fluid. Since the pulsations are in the audio frequency range, they are termed acoustic noise. This pump induced acoustic noise can generate standing waves of pressure and flow throughout the pressure system in a manner similar to those observed in organ pipes and electrical transmission lines. When the pulsation frequency coincides with natural frequencies in the system, hydraulic resonance occurs. This creates large pressure peaks and destructive vibratory conditions can result.

The HSFR program computes pump speeds for which hydraulic resonances occur at element locations in the system. Component modifications can be rapidly evaluated to correct unacceptable resonant conditions. Potential problems resulting from pump acoustical noise can therefore be minimized in the design stage.

5.2.2 Hydraulic Test Configuration

FC-1 system in the LHS simulator was evaluated. A schematic diagram showing component and line arrangements used for the computer analysis is presented in Figure 51. The hose normally connected to the pump discharge port was replaced with a -8 size titanium tube approximately 37 in. long. This was done to permit a clamp-on type pressure transducer to be used. Collectively, the components and lines made up a 53 element model. The computer input data that physically described these elements is shown in abbreviated form in Figure 52. An explanation of the data format is given in reference 15. MIL-H-83282 fluid properties for the program test conditions of 8000 psi and +145°F were:

Density	0.00007870 lb-sec^2/in^4
Viscosity	0.02468 in^2/sec
Bulk Modulus	288,000 psi

The laboratory instrumentation consisted of a spectrum analyzer and a clamp-on piezoelectric pressure transducer. Instrumentation details are given in section 4.4.1. Transducer response verification is shown in Appendix B. Peak pressure data were measured with the spectrum analyzer while pump speed was varied from 2000 to 6000 rpm. Pump speed was indicated on an electronic frequency counter. Fluid temperature was measured with a thermocouple near the pump suction port. Discharge fluid temperature was determined using the known temperature rise due to fluid compression (17°F @ 8000 psi). Fundamental, first, and second harmonic data were recorded at 100 rpm increments at locations of 12, 20, and 32 inches from the pump outlet. The 37 in. long hard line from the pump to the check valve was divided into smaller line length elements (such as P6 and P7) for programming at specific locations.

Computer data designated as harmonic No. 1 was actually the fundamental frequency and harmonic No. 2 was the first harmonic of the fundamental. This terminology was used for programming convenience.

5.2.3 Test Results

The laboratory test data was overplotted on the computer printouts generated by the HSFR program. Figures 53, 54, and 55 provide comparisons of pressure amplitudes at the fundamental frequency for locations 12 (P6), 20 (P7), and 32 (P10) inches downstream from the pump outlet. Amplitudes of the predicted fundamental correlated well with the measured data above pump speeds of 3600 rpm. At element P6 the predicted and actual resonant peaks were nearly identical near maximum pump speed of 5900 rpm. Correlation was also excellent at P7 near 5900 rpm. Further downstream at P10, the predicted values were higher than the measured values.

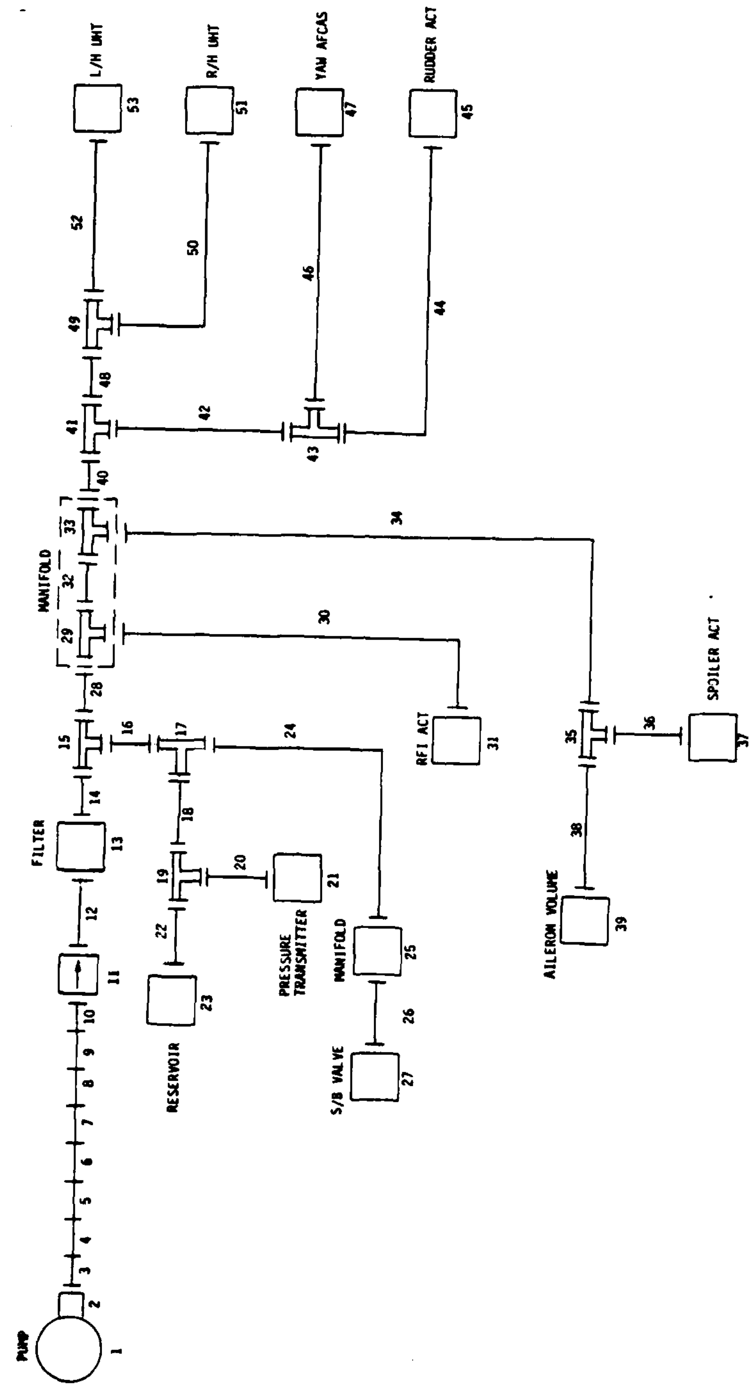

FIGURE 51. Model schematic for HSFR program

LHS FCL HYDRAULIC SYSTEM FREQUENCY RESPONSE 2CSEPT85

RESPONSE IS CALCULATED FROM 2000.00 TO 6000.00 R.P.M. IN INCREMENTS OF 50.00 R.P.M.

RESPONSE IS PLOTTED FOR HARMONIC NUMBER , 2

NUMBER OF PUMPING ELEMENTS= 9.

USER DEFINED FLUID DATA

3000.0 PSIG

TEMPERATURE (DEGREES F)	DENSITY (GR/ML)	DENSITY (LB/FT**3)	DENSITY (LB*SEC**2/IN**4)	VISCOSITY (CENTISTOKES)	VISCOSITY (IN**2/SEC)	BULK MODULUS (PSI)
145.00	.8410	52.51	.7870E-04	15.92	.2468E-01	250000.

ELEMENT NUMBER ****************************SYSTEM ELEMENT INPUT DATA****************************

	N TYPE	K TYPE	.....	.....	.....	PHYSICAL DATA	.....	.....	.....	.....
1	9	21	.003	.425	.850	.850	.429	.081	.083	
			.08300	12.00000	4.62000	4.25000	31.70000	33.30000	20.70000	22.30000
			90.00000	.05400	.30800	1.45000	.00023	125.00000	150.00000	.43340
2	3	0	.010	0.030	0.200	0.030	0.000	0.000	0.000	
3	1	0	2.190	.500	.251	15000000.030	0.000	0.000	0.000	
4	1	0	5.000	.500	.251	15000000.030	0.000	0.000	0.000	
5	1	0	5.000	.500	.051	15000000.030	0.000	0.000	0.000	
6	1	0	9.000	.500	.251	15000000.030	0.000	0.000	0.000	
7	1	0	2.000	.500	.251	15000000.030	0.000	0.000	0.000	
8	1	0	5.000	.500	.251	15000000.030	0.000	0.000	0.000	
9	1	0	5.000	.500	.251	15000000.030	0.000	0.000	0.000	
10	1	0	5.000	.500	.251	15000000.030	0.000	0.000	0.000	
11	3	0	.100	0.030	0.200	0.030	0.000	0.000	0.000	
12	1	0	75.000	.500	.251	15000000.030	0.000	0.000	0.000	
13	3	0	5.000	0.030	0.200	0.030	0.000	0.000	0.000	
14	1	0	.500	.500	.251	15000000.030	0.000	0.000	0.000	
15	6	12	0.000	0.030	0.200	0.030	0.000	0.000	0.000	
16	1	0	22.000	.500	.251	15000000.030	0.000	0.000	0.000	
17	6	6	0.000	0.030	0.200	0.030	0.000	0.000	0.000	
18	1	0	30.000	.183	.020	15000000.030	0.000	0.000	0.000	
19	6	2	0.000	0.030	0.200	0.030	0.000	0.000	0.000	
[illegible]	[illegible]	0	21.000	.183	.020	15000000.030	0.000	0.000	0.000	
			[illegible].000	0.030	0.200	0.030	0.000	0.000	0.000	
[illegible]				.183	.020	15000000.030	0.000	0.000	0.000	
41	6	6			0.200	0.030	0.000	0.000	0.000	
42	1	0	21.000			[illegible]000.030	0.000	0.000	0.000	
43	6	2	3.000	0.030			0.000	0.000	0.000	
44	1	0	65.000	.133	.020			0.000	0.000	
45	14	0	1000.000	.041	0.200	0.000			0.000	
46	1	0	60.000	.133	.020	15000000.030	[illegible]		[illegible]	
47	14	0	1000.000	.163	0.000	0.030	0.000			
48	1	0	19.000	.375	.030	13000000.030	0.000	0.000		
49	6	2	0.000	0.000	0.000	0.030	0.000	0.000	0.000	
50	1	0	100.000	.250	.026	15000000.030	0.000	0.000	0.000	
51	14	0	1000.000	.061	0.000	0.030	0.000	0.000	0.000	
52	1	0	100.000	.250	.026	15000000.030	0.000	0.000	0.000	
53	14	0	1000.000	.061	0.000	0.030	0.000	0.000	0.000	

3 P PLOTS FOR INPUT TO ELEMENT NUMBERS 5 7 10

FIGURE 52. Computer input data

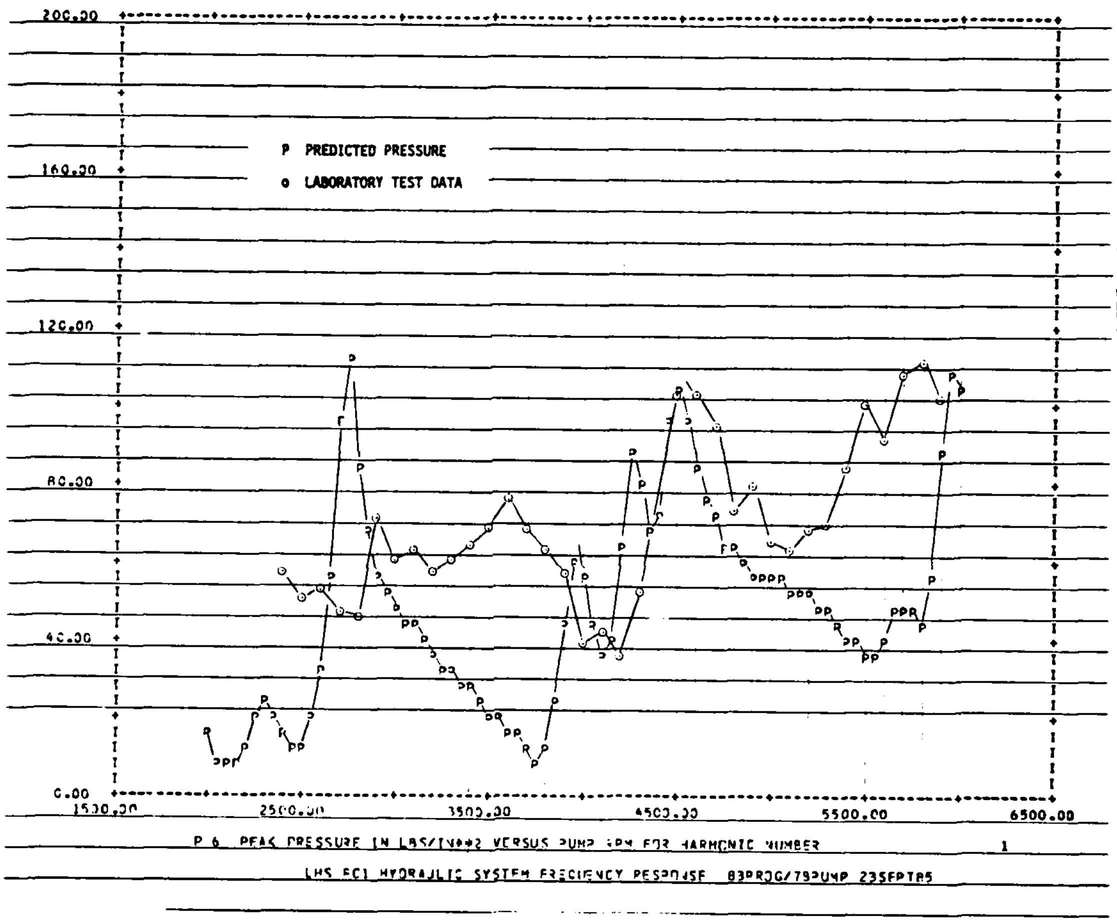

FIGURE 53. Peak pressure vs pump RPM at element 6 (12 inches), fundamental

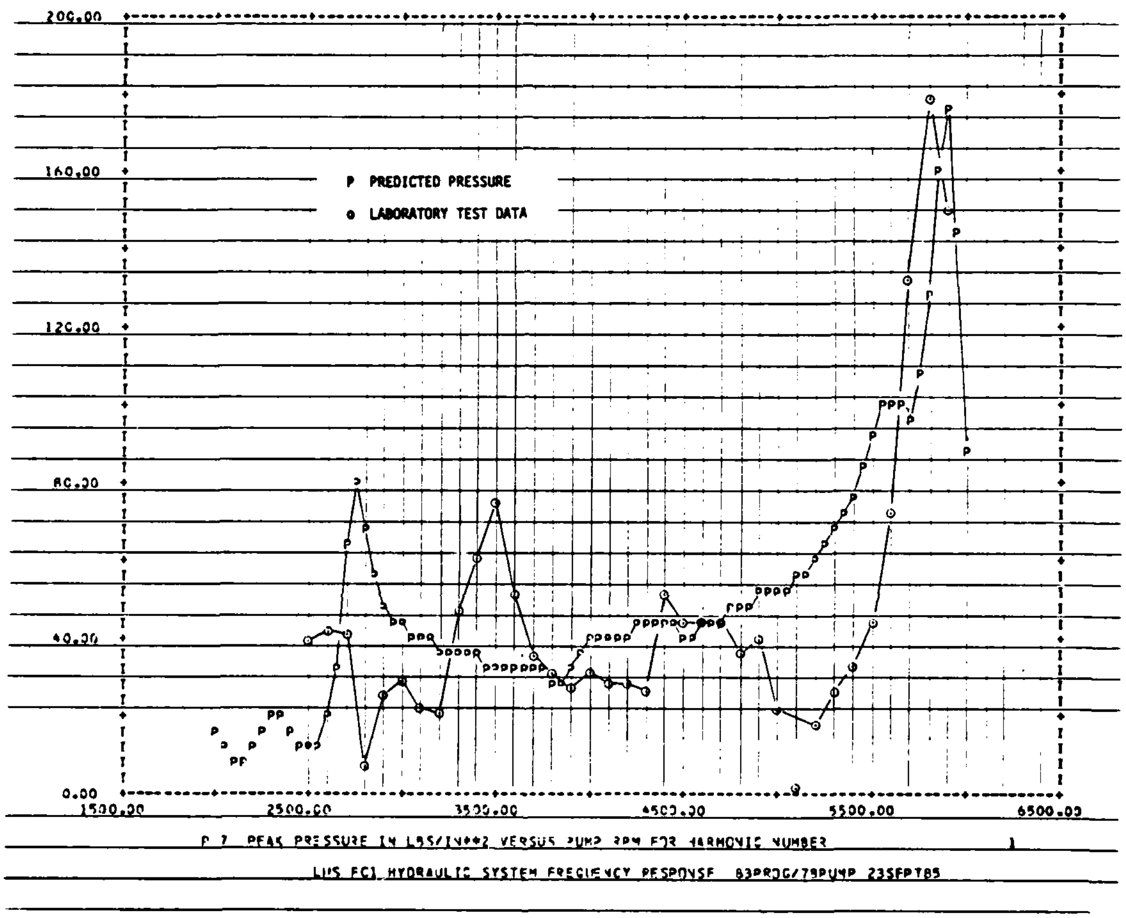

FIGURE 54. Peak pressure vs pump RPM at element 7 (20 inches), fundamental

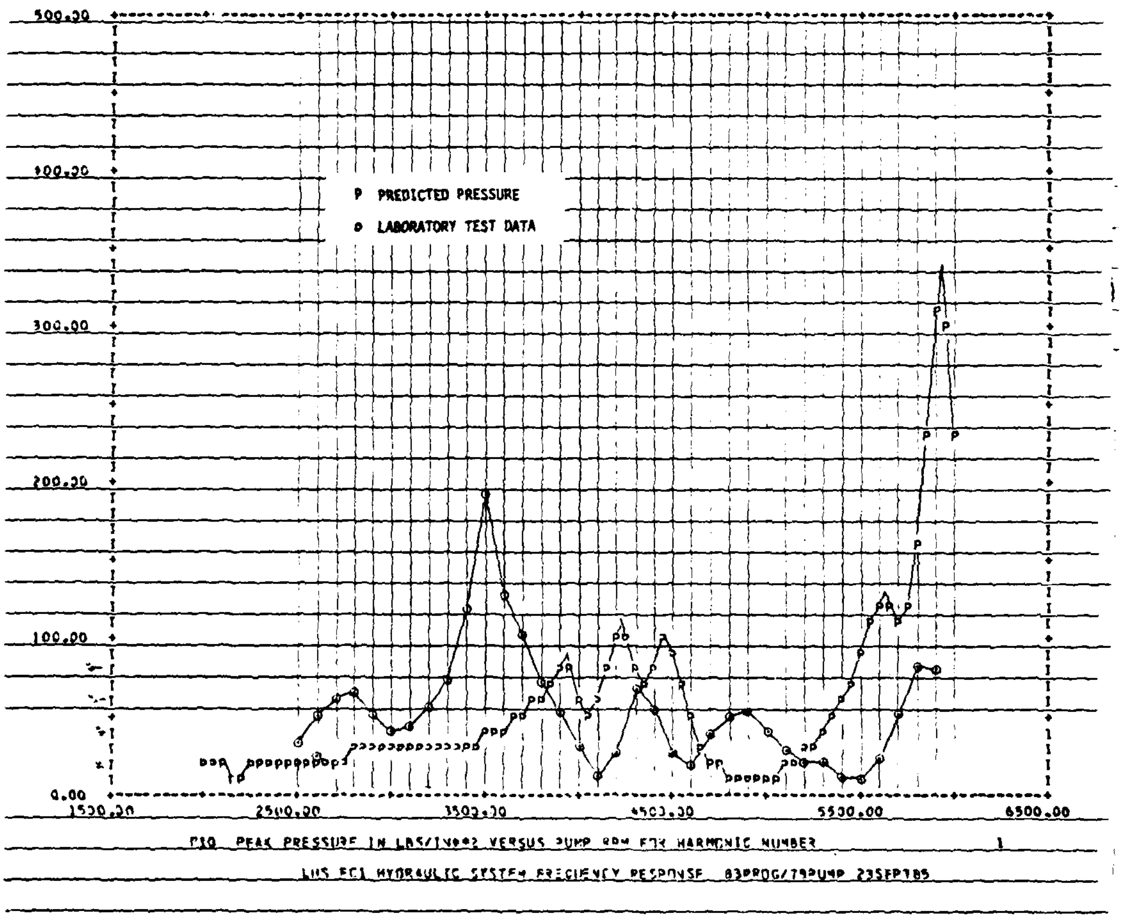

FIGURE 55. Peak pressure vs pump RPM at element 10 (32 inches), fundamental

Figures 56, 57, and 58 show first harmonic data comparisons at elements P6, P7, and P10, respectively. Agreement between the measured and predicted data at P6 was excellent except at 5800 rpm. The data for location P7 showed good correlation of resonant frequencies, but predicted amplitudes were higher than measured values. The data for P10 were similar to P7.

The test results show that the predictive capabilities of the HSFR program applied to the full scale LHS simulator were generally good. Excellent correlation with measured data was observed at some element locations. Predictions of resonant frequencies appeared consistent, but amplitude predictions tended to be on the high side. All measured peak pressures were below the 200 psi peak maximum allowable.

Effort was expended to minimize possible analytical errors by varying fluid temperatures, bulk modulus, and viscosity. The predicted peak amplitudes were relatively insensitive to the changes made. Additional effort needed to improve the modeling capabilites of the HSFR program was beyond the Phase II scope of work.

5.3 HYDRAULIC TRANSIENT RESPONSE ANALYSIS

5.3.1 Background

Operation of hydraulic components such as actuators and solenoid valves cause pressure and flow transients to propagate throughout system plumbing. The waterhammer effect produced by suddenly stopping fluid flow can result in a large pressure peak traveling from the point of origin back to the pressure source (pump). Severe transients can also occur when high pressure fluid is suddenly ported into a cavity filled with low pressure fluid.

The HYTRAN program simulates, by mathematical modeling, the dynamic response of hydraulic systems to sudden changes in load flow demand. System transient pressures and flows induced by the opening and closing of valves can be predicted. The program users guide, reference 15, contains detailed instructions on the preparation of an input data set that models the hydraulic system. Building-block subroutines are provided to mathematically represent transmission lines, branches, and a large variety of components. Motion of internal valve parts programmed as a function of time represent inputs to the program. Time histories of pressures and flows at any point in the system constitute the usual outputs.

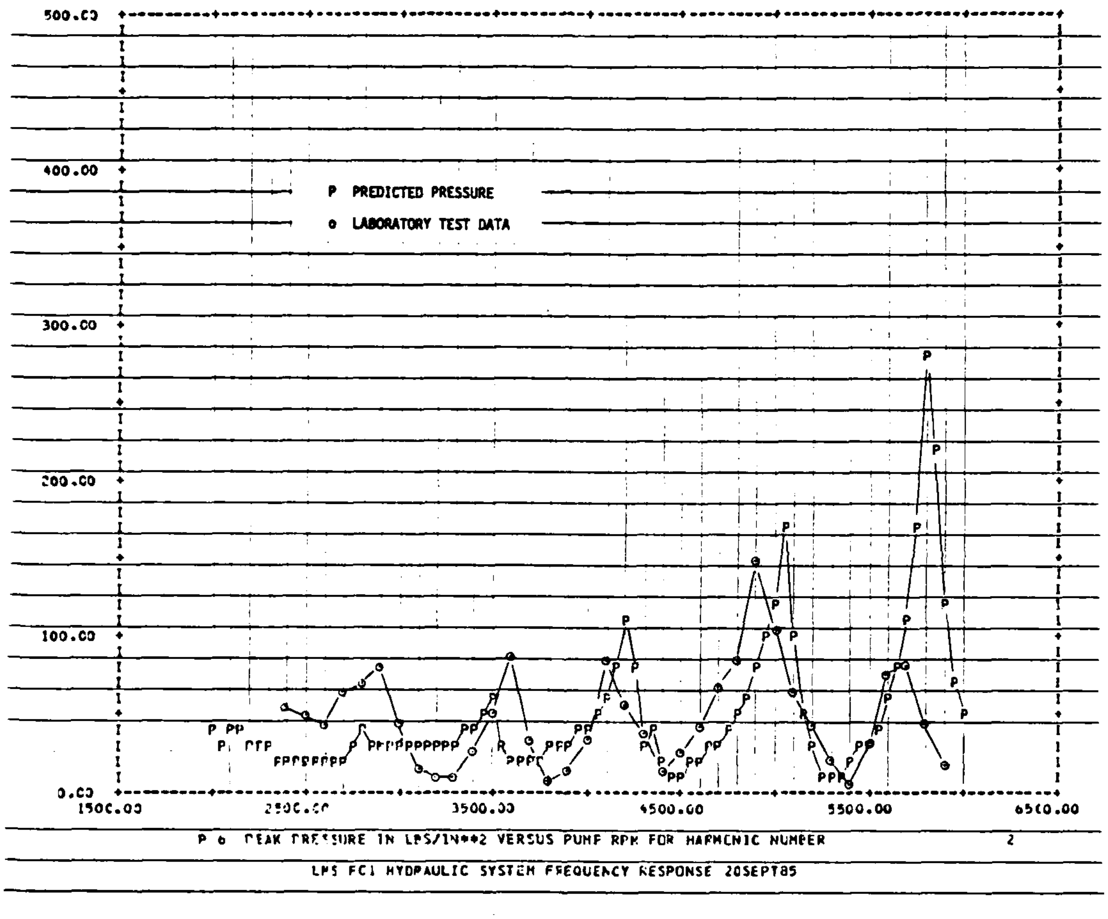

FIGURE 56. Peak pressure vs pump RPM at element 6 (12 inches), 1st harmonic

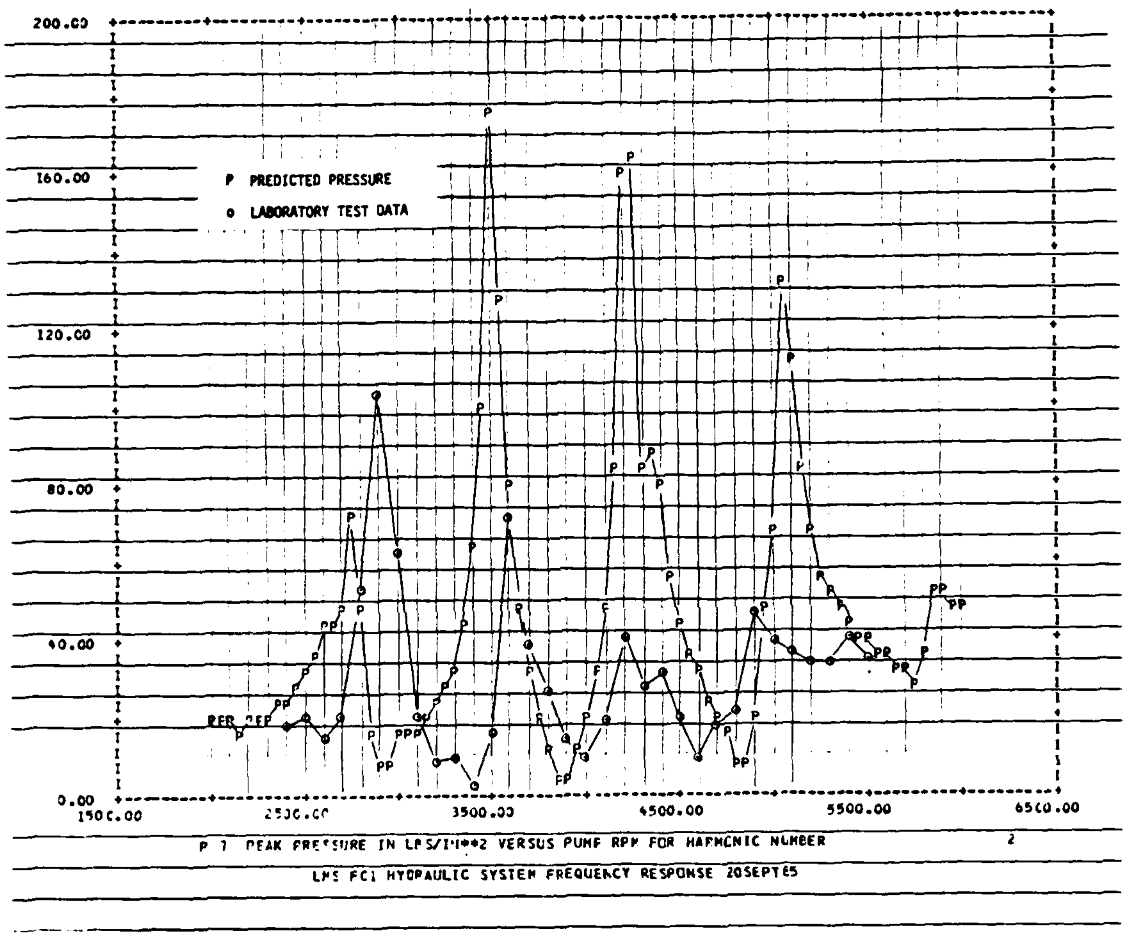

FIGURE 57. Peak pressure vs pump RPM at element 7 (20 inches), 1st harmonic

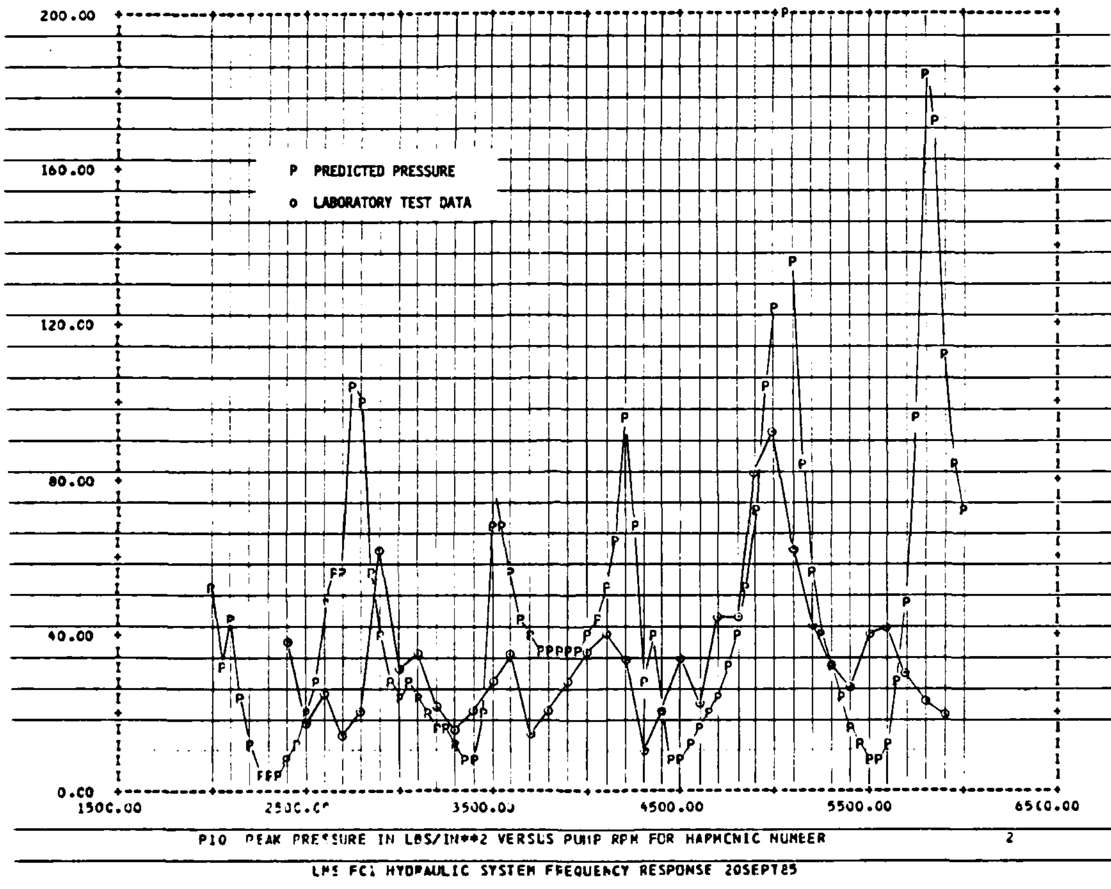

FIGURE 58. Peak pressure vs pump RPM at element 10 (32 inches), 1st harmonic

5.3.2 Hydraulic Test Configuration

A fast-acting, 3-way solenoid valve used to control flow to the AFCS yaw actuator was selected for analyses. Rapid opening action of this valve induced large pressure transients in the line connecting the valve output port to the actuator (see section 4.4.2). A 2 gpm restrictor was used to provide damping needed to reduce the pressure surge. Two configurations were evaluated: 1) Bendix valve with and without the restrictor in the inlet port, and 2) Parker Bertea valve with and without the restrictor in the outlet port (see Table 2). Both valves are pilot operated, but employ different operating and internal sealing principles. A valve opening time of 0.005 sec was assumed for the Bendix valve; an opening time of 0.010 sec was used for the Parker Bertea valve.

A schematic diagram of hydraulic circuitry used to simulate the valve/actuator installation is shown in Figure 59. Only direct connections from the pump to the valve/actuator were required because other portions of FC-1 system would have little effect on the transient pressure due to 1) the remote location of the AFCS actuator and 2) the fact that system pressures were stabilized at a low flow condition.

5.3.3 Test Results

The laboratory test data was overplotted on the computer printouts generated by the HYTRAN program. This provides a direct comparison of actual versus predicted pressures. Figures 60 and 61 present Bendix valve data. Figures 62 and 63 cover the Parker Bertea valve. Correlation between actual and predicted pressure transients was excellent. Rise times, pressure peaks, frequency, and damping were all within normal experimental error of 5 to 10%. The HYTRAN program was thus considered to be well suited for analysis of transients in 8000 psi hydraulic systems.

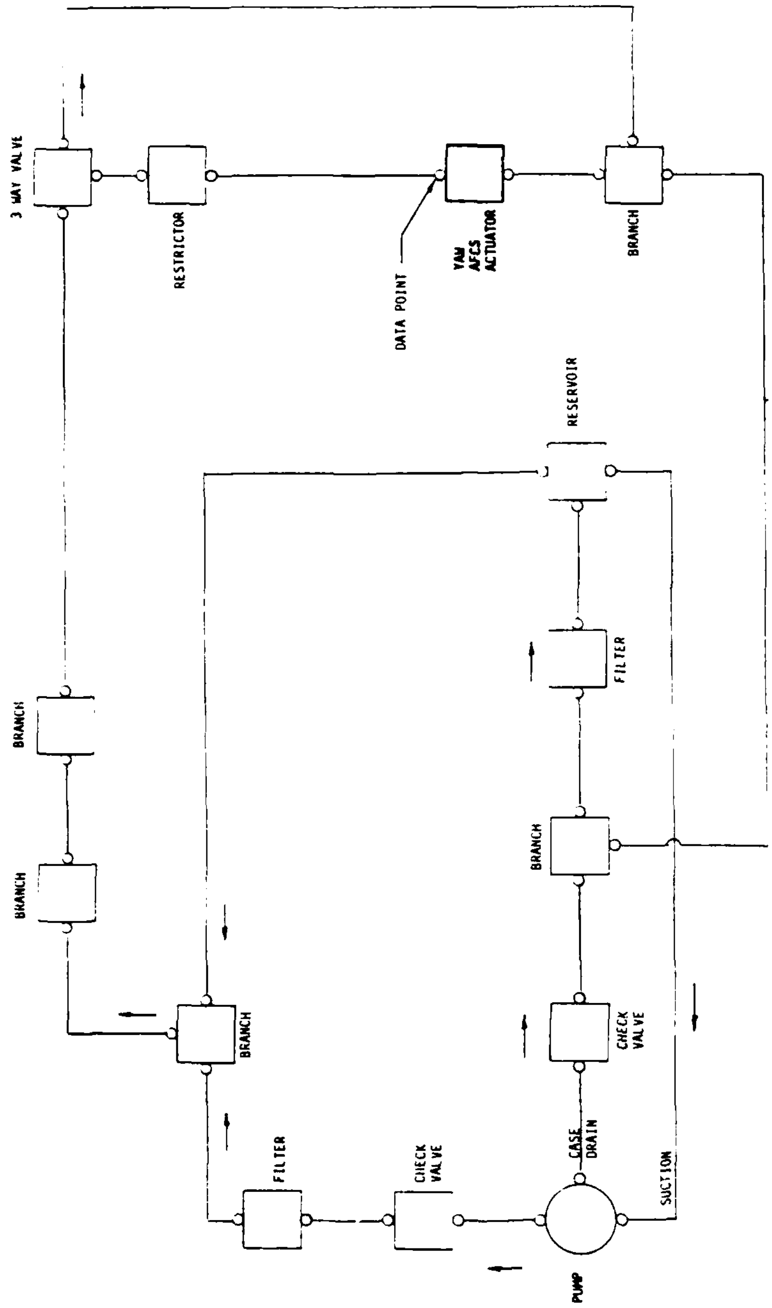

FIGURE 59. Model schematic for HYTRAN program

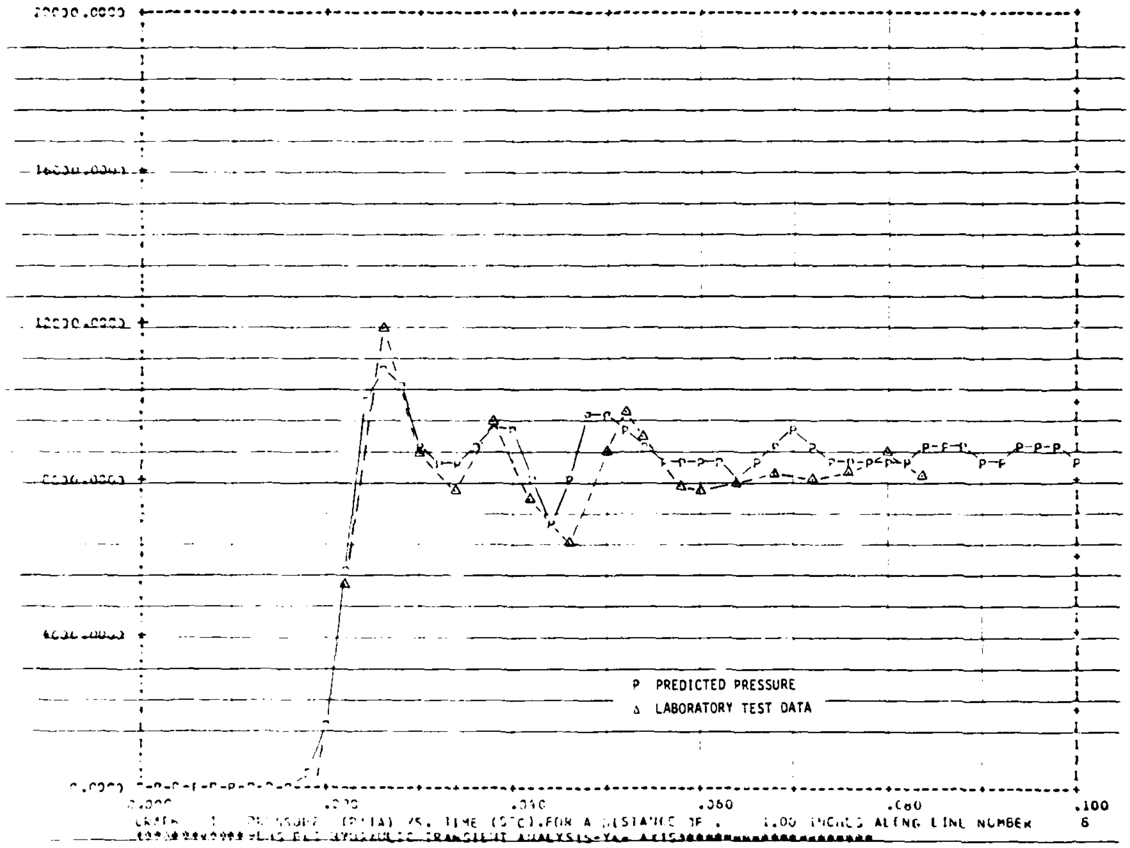

FIGURE 60. Pressure transient at AFCS yaw actuator, Bendix valve, no restrictor

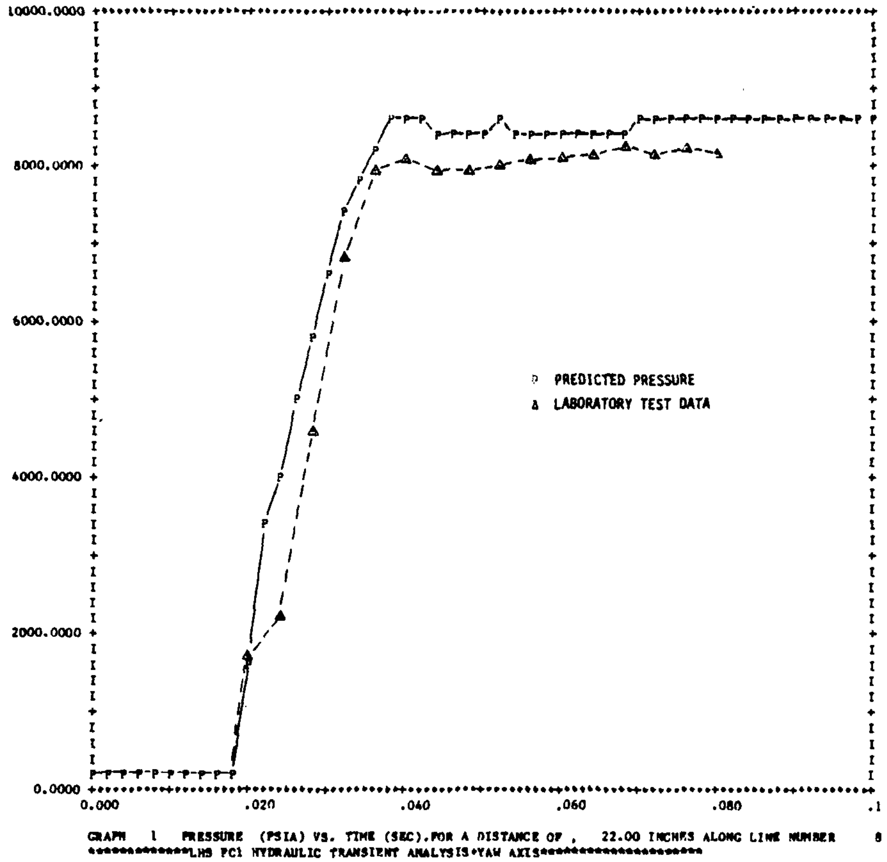

FIGURE 61. Pressure transient at AFCS yaw actuator, Bendix valve, restrictor in port 'P'

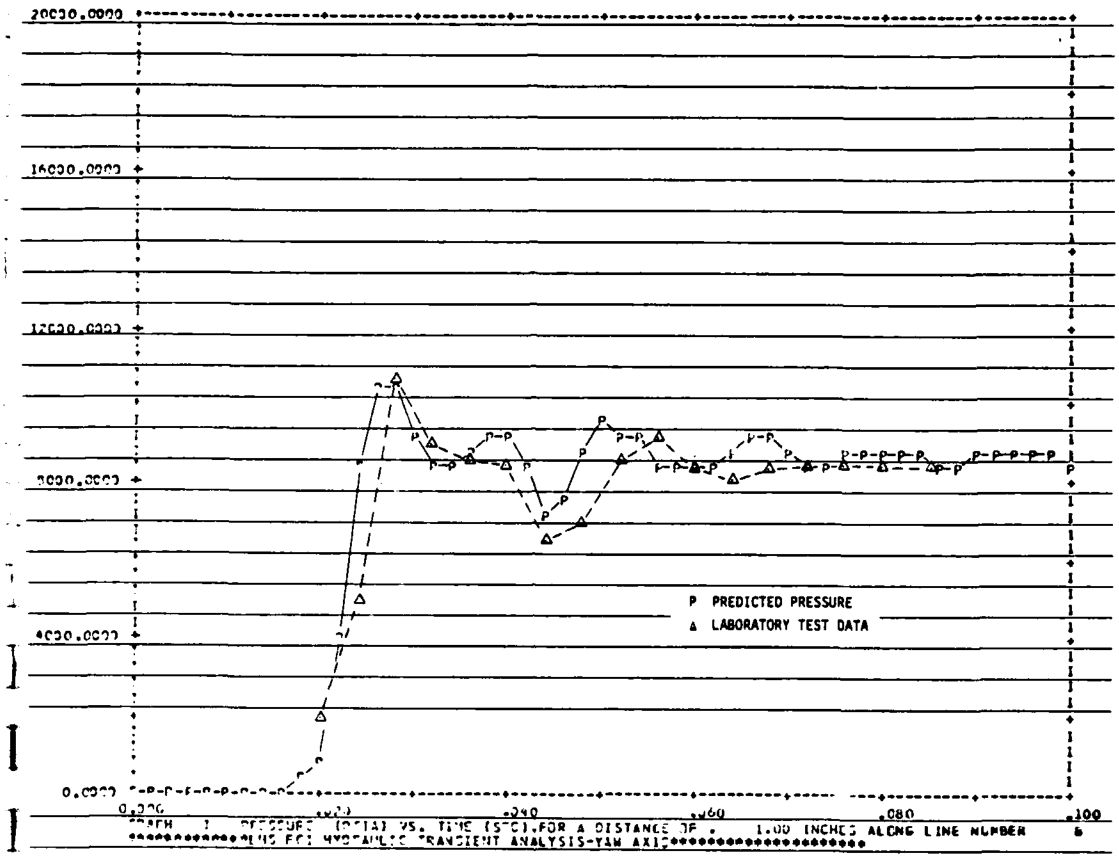

FIGURE 62. Pressure transient at AFCS yaw actuator, Parker Bertea valve, no restrictor

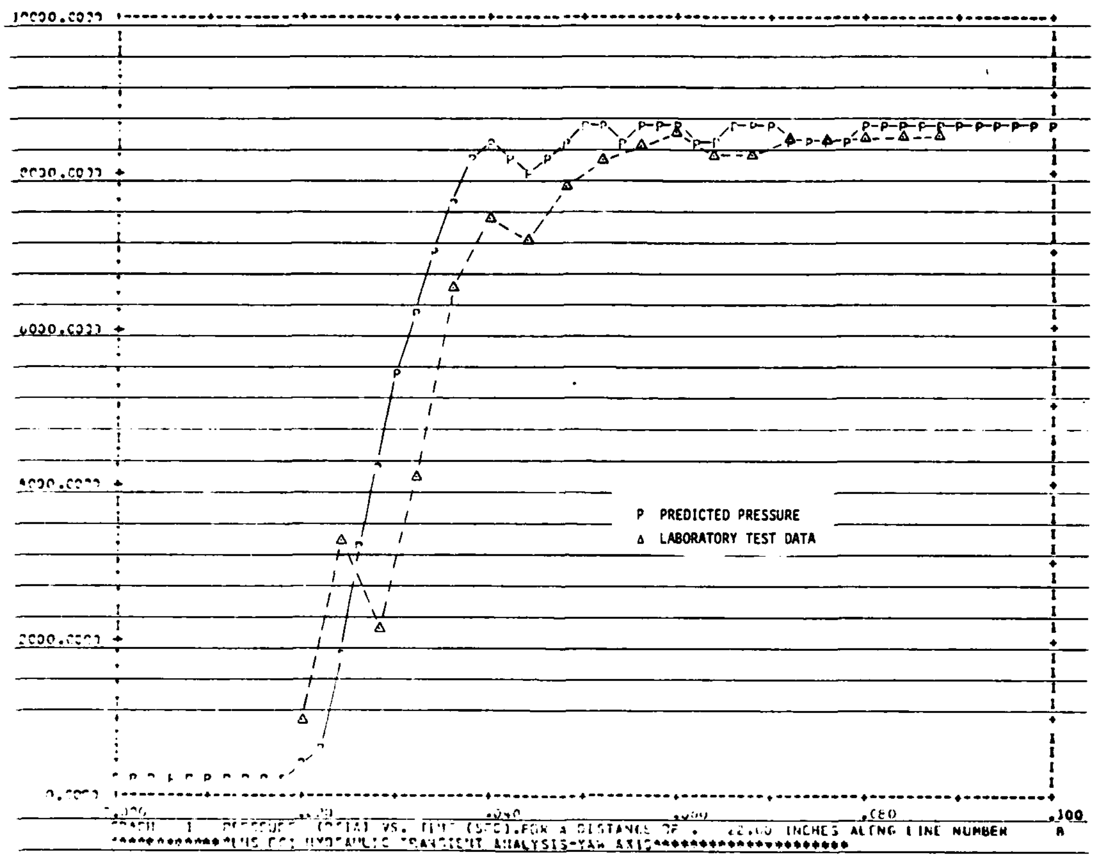

FIGURE 63. Pressure transient at AFCS yaw actuator, Parker Bertea valve, restrictor in port 'C'

6.0 SYSTEM WEIGHT AND SPACE ANALYSIS

6.1 INTRODUCTION

The basic purpose of LHS technology is to reduce the weight of the installed hydraulic system. In addition, reduction in space occupied by smaller LHS components permits more compact installations, and in some cases, make possible design approaches not practical with larger, lower pressure components. A major objective of the LHS program was to verify the projected 30% weight and 40% volume reductions achieved by advancing to an 8000 psi operating pressure level. Weight and space savings calculated in Phase I (see reference 11) were updated to reflect actual hardware weight measurements taken in Phase II.

6.2 APPROACH

6.2.1 General Guidelines

Since the A-7E 8000 psi system configuration differed somewhat from the A-7E 3000 psi system, the A-7E weight data were re-arranged to permit a direct comparison between the two systems. The EQUIVALENT 3000 psi system was defined as the existing A-7E system with changes incorporated to make it functionally identical to the 8000 psi simulator system. Analysis guidelines are detailed in reference 11.

Component weights determined in Phase I included some actual measurements, but most values were calculated since the hardware was not available. All major and minor components on the LHS simulator (except tubing and fittings) were weighed in Phase II. Pump weight was updated to reflect incorporation of larger pintle bearings. (The first re-designed pump was received in September, 1985.). The Phase II weight update also includes weight adjustments outlined in the next section.

6.2.2 Weight Adjustments

Additional weight savings can be achieved by incorporating adjustments made to reflect improvements that could readily be made in a production aircraft application. The adjustments were included in both the 3000 psi and 8000 psi system weight determinations, but were not included in the volume calculations because of their negligible effect. The adjustments are outlined below and tabulated in Appendix E.

- More efficient reservoir design. This would produce an estimated savings of 7.3 lb in the EQUIVALENT 3000 psi system and 11.6 lb in the 8000 psi system.

- Match the 8000 psi UHT actuator output force to the 3000 psi actuator by reducing the LHS actuator barrel diameter one O-ring size. This would result in no change in the EQUIVALENT 3000 psi system and an estimated 2.0 lb decrease in the 8000 psi system.

- Use castings/forgings instead of "hog-outs". This would not affect the 3000 psi weights and would decrease the 8000 psi system weight by an estimated 6.3 lb. Approximately 3 lb was attributed to valves and 3.3 lb to actuators.

- Use shrink-fit control valves on the 8000 psi actuators instead of standard spool/sleeve valves. This would produce no change in the EQUIVALENT 3000 psi system and provide an estimated 12.3 lb savings in the 8000 psi system. Shrink-fit valves were used in the LHS spoiler and RFI actuators and the weight savings are included in the weight analysis. If shrink-fit valves were used in the aileron, UHT, and rudder actuators, an additional weight decrease could be achieved as follows:

Aileron actuator (2)	4.43 lb x 2 =	8.86
UHT actuator (2)	1.14 lb x 2 =	2.28
Rudder actuator	1.15 lb x 1 =	1.15
		12.29 lb

- Run pumps at higher speeds than is possible with the current A-7E gear box. This would produce an estimated 3.6 lb decrease in the EQUIVALENT 3000 psi system and a 9.7 lb savings in the 8000 psi system.

6.3 RESULTS

Detail weight and space determinations are presented in Appendix E. Weight and space savings summaries are given on Tables 29 and 30. Weight savings achieved were:

Total weight of EQUIVALENT 3000 psi system	644.4 lb
Total weight of LHS 8000 psi system	431.3 lb
Weight reduction	213.1 lb
Weight savings	33.1%

Space savings achieved were:

Total volume of EQUIVALENT 3000 psi system	8173 in^3
Total volume of LHS 8000 psi system	5207 in^3
Volume reduction	2966 in^3
Space savings	36.3%

TABLE 29. Weight savings summary

	EQUIVALENT 3000 psi System	Percent of Sys. Weight	LHS System	Percent Red. in Comp. Wt.	Percent Red. in Sys. Wt.
Actuators	303.9	47.2	231.9	-23.7	-11.2
Pumps	26.2	4.1	27.3	+4.2	+0.2
Reservoirs	43.3	6.7	37.2	-14.1	-0.9
Tubing	75.9	11.8	30.2	-60.2	-7.1
Fittings	36.9	5.7	11.8	-68.0	-3.9
Fluid	76.0	11.8	38.9	-48.8	-5.8
Misc.	82.2	12.7	54.0	-34.3	-4.4
	644.4 lb	100%	431.3 lb		-33.1%

TABLE 30. Volume savings summary

	EQUIVALENT 3000 psi System	Percent of Sys. Volume	LHS System	Percent Red. in Comp. Vol.	Percent Red. in Sys. Vol.
Actuators	3605	44.1	2304	-36.1	-16.1
Pumps	342	4.2	236	-31.0	-1.3
Reservoirs	1634	20.0	1187	-27.4	-5.5
Tubing	1243	15.2	596	-52.0	-7.9
Fittings	319	3.9	145	-54.5	-2.1
Misc.	1030	12.6	739	-28.2	-3.4
	8173 in^3	100%	5207 in^3		-36.3%

The 30% weight savings goal was exceeded; the 40% space savings goal was nearly reached. Weight values are easily obtained using scales. Volume determinations are more difficult, and if calculated, require many approximations. The most accurate and practical method to determine component volume is water displacement; this was not attempted. More accurate and complete volume figures would increase space savings from the reported 36.3% to a value close to the 40% goal.

7.0 RELIABILITY & MAINTAINABILITY ASSESSMENT

7.1 INTRODUCTION

The reliability and maintainability assessment was based primarily on experience gained from laboratory mission/profile testing (see section 4.5). R&M goals in Phase II were to achieve a 15% improvement over current fleet experience with A-7E aircraft. A reliability growth trend analysis was conducted using the test data. Design evaluations were aided by Failure Modes and Effects Analysis (FMEA) and enhanced by test experience.

7.2 FAILURE MODES & EFFECTS ANALYSIS

An FMEA was prepared for the 8000 psi lightweight hydraulic system designed for installation in an A-7E test bed aircraft. The basic purpose of the FMEA was to identify all conceivable failure modes so that design improvement requirements could be determined. The FMEA was prepared using MIL-STD-1629A as a guide. Method 101 of this standard was applied for the basic FMEA. Method 201 was used as a guide in establishing quantitive estimates relating to criticality of function. The FMEA presented in this report was expanded from an earlier version prepared by Eagle Technology, Inc. (E-Tech) based on Phase I effort, reference 11. The update reflects system changes, laboratory failure analyses, and technical inputs from design engineers. The pump analysis was based on an FMEA prepared by Vickers Corporation. The expanded FMEA is presented in Appendix F.

The predicted failure rate summary given by the FMEA can be used to project total aircraft Mean Flight Hours Between Failures (MFHBF). Table 31 presents a summary of the MFHBF for each functional subsystem of the A-7E lightweight hydraulic system. The predicted MFHBF is 53.2 hours -- a 17.2% improvement over the operational MFHBF of 45.4 hours for the A-7E 3000 psi system. This is consistent with the experience achieved during simulator mission/profile cycling, see Section 7.3.

An analysis was made of the failure rate contribution of components in the 8000 psi system. The components and their respective contributions are listed in Table 32. For comparison, 10 components which contribute over 75% of the failures in the operational A-7E 3000 psi system are given in Table 33.

Potential leak problems in 8000 psi systems were addressed early in Phase I, and development work toward seal improvement has continued to prove successful in Phase II. The LHS simulator leak rates are reflected in the predictions made in the FMEA. LHS coil tubing, designed to replace

TABLE 31. Lightweight hydraulic system function summary

SYSTEM CODE	FUNCTION	FAILURE RATE*	MEAN FLIGHT HOURS BETWEEN FAILURES
01	FC-1 power	3784	264
02	FC-2 power	4171	240
03	Speed brakes	1129	886
04	Roll feel iso.	727	1376
05	Autopilot system	1048	954
06	Aileron & spoiler	3065	326
07	L.E. flaps	2318	431
10	Rudder	569	1757
11	Unit horizontal tail	593	1686
--	Fittings/tubing	1386	--
SUMMARY		18790	53.2

* Failures per million flight hours

TABLE 32. Failure rate contribution to 8000 psi hydraulic system

ITEM	% CONTRIBUTION
Coiled tubing	16.4
Filters	14.9
Quick disconnects	13.9
Hoses	7.3
AFCS	5.5
Aileron actuators	5.0
Pumps	4.3
Tubing/fittings	4.0
Selector valves	3.3
Pressure transmitters	3.3
UHT actuators	3.2
Reservoir	2.8
Spoiler actuators	2.1
L.E. flap actuators	1.8
Restrictors	1.7
Swivel joints	1.6
RFI actuator	1.6
Rudder actuator	1.6
Relief valves	1.6

ITEM	% CONTRIBUTION
Extension units	23.0
Disconnects	11.4
Filters	10.6
Tubings/fittings	6.5
AFCS actuators	6.5
Aileron actuators	5.6
Swivel joints	4.5
Pumps	4.0
Pressure transmitter	2.7
UHT actuators	2.6

TABLE 33. Failure rate contribution to A-7E hydraulic systems

the high leak rate extension units on the A-7E aircraft, were predicted to continue as the highest failure rate contributor in the A-7E 8000 psi system. Coil tubing has valuable potential, however, and with continued development effort, may be used successfully in the A-7E applications. A successful design would reduce the number of reported failures significantly. The coil tube failure rate assigned in this study was influenced by LHS simulator experience.

An important aspect of Tables 32 and 33 is the presence of items which may be considered as minor components. Quick disconnects, five of which are used in each 8000 psi system, have the same number of seals as their 3000 psi counterparts. "Leaking" has been identified as contributing to 89% of the QD failure rate. Filters appear to have a high failure rate partly because the general definition of failure includes "clogged", "metal in filter", "no-go indication", and "low output" -- all of which are evidence of the filter doing its job. "Leaking", however, accounts for 78% of filter failure modes.

7.3 R&M EVALUATION

A quantitative assessment of operational R&M based on a laboratory development program is necessarily dependent upon subjective judgement. The test components do not experience an aircraft environment which probably would induce more failures. On the other hand, the laboratory equipment is under constant surveillance, and failures are detected long before they would be apparent in service use. Evaluation of failures that occurred during the program disclosed both quality control and design problems. Most of these took place early in the testing and fixes were incorporated before cycling was resumed. Such experience is applicable to the concept and theory of reliability growth development. Thus, reliability trends were established using growth methodology as a basis for the reliability assessment.

7.3.1 Summary of Simulator Failures

The reliability assessment was developed on the basis of mission/profile testing conducted on the LHS simulator. Table 34 is a summary listing of failures which occurred during mission/profile cycling and which were used for the reliability assessment. The list excludes failures which occurred in the simulator load system, non-hydraulic related mechanical components, and failures which did not affect the function of a component while operating in the simulator. Coiled tube failures were also excluded because they require additional development effort, and the application requirement is peculiar to the A-7 aircraft. A log of pertinent events relative to mission/profile testing is presented in Appendix A. A summary analysis of failures reported during Phase II is given in Table 35.

7.3.2 Reliability Trend Analysis

The reliability trend analysis was developed in accordance with concepts for reliabily growth given in MIL-HDBK-189, Reliability Growth Management. The growth concept projects that Mean-Time-Between-Failure (MTBF) plotted versus time will approximate a straight line (using log-log scaling) if corrections are incorporated following each failure. The slope of the line, showing cumulative MTBF as a function of time, is indicative of the aggressiveness and completeness of the corrective actions taken.

The data of Table 34 are plotted on log-log scales in Figure 65. Operating time for the high pressure components was increased by a factor of 2.7 since cycles were accumulated at a rate 2.7 times faster than would be experienced in an operational aircraft. Actual simulator hours were used for low pressure components. A least square linear regression line was drawn through the data points. The end point of the curve at 1620 hours (600 simulator hours x 2.7 acceleration factor) yields a cumulative MTBF of 79 hours. Since this figure is based on accumulative data, and includes failures which have been corrected, it is not representative of

TABLE 34. Summary of LHS simulator failures

COMPONENT	SIMULATOR HOURS	FAILURE	LOCATION/REMARKS
O-ring	14	Leak	Rudder AFCS selector valve; loose fitting
Check valve	108	Leak	Speed brake circuit check valve; wrong size backup ring
Quick disconnect	138	Leak	FC-1 pump case drain QD; old O-ring
O-ring	172	Rupture	Rudder actuator control valve; loose fitting
O-ring	190	Leak	FC-1 pressure manifold -5 end port
O-ring	212	Leak	FC-1 pump case drain boss seal
O-ring	254	Leak	Rudder actuator control valve; aluminum housing port thread stretch
Relief valve	272	Leak	FC-1 reservoir, low pressure; replaced
Relief valve	304	Leak	FC-2 reservoir; low pressure; re-adjusted
RH UHT act'r	310	Malfunction	No output with 2% inputs; slot in spool 0.007" out-of-tolerance
LH UHT act'r	311	Malfunction	Running rough @+200°F; oversize o-ring binding
Check valve	339	Leak & fatigue	FC-1 pump discharge check valve; backup ring extruded & poppet failed
Hose	362	Leak	FC-2 pump discharge; swaged fitting
LH UHT Act'r	372	Malfunction	Running rough @+200°F; spool/sleeve temperature differential expansion
O-ring	380	Leak	FC-2 pump case drain filter static seal; permanent set
Check valve	452	Malfunction	FC-1 pump discharge check valve; bore pitting & erosion
LH UHT act'r	478	Fatigue	Base end support fitting; under-design

NOTE: Summary excludes coil tubing failures and non-hydraulic related mechanical failures.

TABLE 35. Failure reports and analysis summary

DATE	COMPONENT PART NO.	TEST	TIME OF FAILURE	FAILURE DESCRIPTION	PROBABLE CAUSE/RECOMMENDATIONS/ACTION
11-16-81	PUMP CLAMP, AEROQUIP P/N 4563-350	PUMP PERFORMANCE	---	FAILED WHILE LOOSENING SUCTION PORT FITTING ON FC-1 PUMP. CRACK ALSO FOUND IN FC-2 PUMP CLAMP.	IMPROPER APPLICATION OF CLAMP. HEAVIER DUTY CLAMP NOW BEING USED.
12-13-82	ONE WAY RESTRICTOR, GAR KENYON P/N 95461-1	SYSTEM PROOF PRESSURE	---	EXCESSIVE EXTERNAL LEAKAGE.	LIP SEAL FITTING SURFACE MACHINED TO 8 1/2 DEGREE ANGLE. SHOULD HAVE BEEN 3 DEGREES.
2-24-83	AILERON ACTUATOR, VOUGHT P/N 83-00221	PERFORMANCE CHECK	---	EXCESSIVE INTERNAL LEAKAGE. ACTUATOR PREVIOUSLY USED IN PHASE I COMPATIBILITY TEST AND VOUGHT LOW TEMPERATURE PERFORMANCE TESTS. SEE TABLE 1.	PISTON SEAL HAD STEEL BACKUP RINGS. SEAL WITH NON-METALLIC BACKUP RINGS INSTALLED. SEE APPENDIX C.
4-12-83	O-RING, AFCS 3-WAY VALVE, MS28778-4	MISSION/ PROFILE	14HR	EXTERNAL LEAK AT BOSS SEAL	FITTING LOOSE.
5-24-83	COIL TUBE, SPOILER FC-1 RET., VOUGHT P/N 83-00298-3	MISSION/ PROFILE	84 HR, 11,300 CYC	CRACKED TUBE	TUBE FATIGUE FAILURE UNDER DEUTSCH SWAGED FITTING. USE OF DEUTSCH FITTINGS ON 3/16 X .035 TITANIUM TUBING NOT RECOMMENDED. USE RESISTOFLEX OR CRYOFIT FITTINGS.
6-24-83	CHECK VALVE, SPEED BRAKE CIRCUIT, CIRCLE SEAL P/N P1-858	MISSION/ PROFILE	108HR	O-RING IN DIAMETRAL SEAL RUPTURED.	WRONG SIZE BACKUP RING. -012 SIZE USED. SHOULD HAVE BEEN -013.
6-27-83	COIL TUBE, SPOILER FC-1 PRESS., VOUGHT P/N 83-00287-1	MISSION/ PROFILE	112HR 30,500 CYC	LEAK AT SWAGE FITTING	SEE 5-24-83 ABOVE. SWAGED FITTINGS REPLACED WITH CRYOFIT FITTINGS ON 8-2-83.

TABLE 35. (continued)

DATE	COMPONENT PART NO.	TEST	TIME OF FAILURE	FAILURE DESCRIPTION	PROBABLE CAUSE/RECOMMENDATIONS/ACTION
8-2-83	QUICK DISCONNECT, PUMP CASE DRAIN, AEROQUIP P/N 3305-6	MISSION/ PROFILE	138HR	LEAKING.	OLD LAB PART USED IN PHASE I. REPLACE WITH NEW PART.
1-23-84	COIL TUBE, SPOILER FC-2 PRESS., VOUGHT P/N 83-00288-1	MISSION/ PROFILE	150HR, 151,000 CYC	LEAK AT MOVING END OF TUBE.	SEE 5-24-83 ABOVE. ROCKWELL DESIGN COIL TUBES WITH RESISTOFLEX FITTINGS INSTALLED IN P1, R1, P2, R2 LINES ON 2-17-84, FIGURE 64. SEE SECTION 4.5.3.10
2-1-84	O-RING, RUDDER CONTR. VALVE, MS-28778-4	MISSION/ PROFILE	172HR	O-RING RUPTURED AT CYLINDER PORT BOSS #3.	FITTING WORKED LOOSE.
2-7-84	O-RING, PRESS. MANIFOLD, MS-28778-5	MISSION/ PROFILE	190HR	LEAKING AT -5 END PORT.	O-RING HAD PERMANENT SET. REPLACE O-RING.
2-27-84	O-RING, FC-1 PUMP, MS-28778-6	MISSION/ PROFILE	212HR	LEAK AT CASE DRAIN BOSS	REPLACE O-RINGS IN ALL PUMP PORTS.
3-14-84	O-RINGS, CONTR, VALVE, MS-28778-4	MISSION/ PROFILE	254HR	O-RING DEBRIS NOTED AT P1, C1, AND C2 PORTS OF RUDDER ACTUATOR CONTROL VALVE HOUSING.	STRETCH IN ALUMINUM HOUSING THREADS ALLOWED O-RING TO EXTRUDE AND GET PINCHED. HOUSING IS A-7 3000 PSI COMPONENT. PART STRESS CHECKED OK FOR 8000 PSI SERVICE. RECOMMEND STEEL HOUSING BE USED.
3-19-84	RELIEF VALVE, VINSON P/N A-63256-3	MISSION/ PROFILE	272HR	FC-1 LOW PRESSURE RELIEF VALVE LEAKING DURING SPEED BRAKE CYCLING.	VALVE HAD PRIOR USE. HISTORY UNKNOWN. VALVE REPLACED WITH VALVE FROM FC-2 SYSTEM.

TABLE 35. (continued)

DATE	COMPONENT PART NO.	TEST	TIME OF FAILURE	FAILURE DESCRIPTION	PROBABLE CAUSE/RECOMMENDATIONS/ACTION
10-11-84	RELIEF VALVE, VINSON P/N A-63256-3	MISSION/ PROFILE	304HR	FC-2 SYSTEM FLUID DUMPED THROUGH VALVE. (VALVE PREVIOUSLY USED IN FC-1 SYSTEM. SEE 3-19-84.)	ADJUST VALVE TO RELIEVE AT 170 PSI (WAS 145 PSI).
10-17-84	RH UHT ACT'R, VOUGHT P/N 83-00211-102	MISSION/ PROFILE	310HR (10HR 34000 CYC)	PISTON NOT MOVING WITH 2% INPUTS.	TOO MUCH FREE-PLAY IN BALL JOINT IN CONTROL VALVE CAUSED DEAD BAND. SLOT IN SPOOL WAS 0.007 OUT-OF-TOLERANCE. RE-WORKED BY ADDING 0.003" CHROME PLATE TO BALL ON INPUT ARM.
10-17-84	COIL TUBE, RFI FC-1 PRESS., VOUGHT P/N 83-00293-1	MISSION/ PROFILE	310HR 1,073,200 CYC	TUBE LEAKING AT FIXED END DEUTSCH FITTING	PROBABLE FATIGUE CRACK IN TUBE IN FITTING SWAGE AREA. INSTALL NEW ROCKWELL DESIGN COIL TUBES AT P1 & R1. CANNOT REPLACE P1 ONLY.
11-2-84	LH UHT ACT'R, VOUGHT P/N 83-00211-101	MISSION/ PROFILE	311HR 2,155,000 CYC (PHASE I & II)	ACTUATOR RUNNING ROUGH. INPUT SHAFT BINDING WHEN FC-2 TEMPERATURES EXCEED +200°F.	WRONG SIZE O-RING ON INPUT SHAFT CAUSED HIGH FRICTION. APPARENTLY INSTALLED TO COMPENSATE FOR MACHINING O-RING GROOVE TOO DEEP. RE-WORKED BY RE-SIZING SEAL GLAND AND PLATING SHAFT FOR -115 SIZE O-RING.
11-26-84	CHECK VALVE, PUMP DISCHARGE, GAR KENYON P/N 95201-5	MISSION/ PROFILE	339HR (489HR, (PHASE I & II)	SLIGHT EXTERNAL SEEPAGE. BACKUP RING EXTRUDED. VALVE HALVES NOT TIGHT. NO LOCK WIRE USED.	POPPET BROKEN IN REDUCED AREA SECTIONS WHERE FLOW HOLES WERE DRILLED. DESIGN UNSATISFACTORY. REPLACE WITH CIRCLE SEAL VALVE P/N P4-858.
12-17-84	HOSE, PUMP DISCHARGE, AEROQUIP P/N DE-6356-102 -0300	MISSION/ PROFILE	362HR (62HR ON HOSE)	LEAK AT SWAGE FITTING NEAR PUMP.	PROBABLE INADEQUATE SWAGE.
1-2-85	LH UHT ACT'R, VOUGHT P/N 83-00211-101	MISSION/ PROFILE	372HR 2,309,900 (PHASE I & II)	ACTUATOR RUNNING ROUGH WITH FLUD TEMPERA-TURES OVER +200°F.	TEMPERATURE DIFFERENTIAL EXPANSION BETWEEN CONTROL VALVE SPOOL AND SLEEVE CAUSED BINDING. SPOOL RE-WORKED TO REDUCE CENTER LAND 0.0001" IN DIAMETER.

TABLE 35. (continued)

DATE	COMPONENT PART NO.	TEST	TIME OF FAILURE	FAILURE DESCRIPTION	PROBABLE CAUSE/RECOMMENDATIONS/ACTION
1-28-85	O-RING, FILTER HOUSING, MS 28775-28	MISSION/ PROFILE	380HR (530+ HR ON O-RING)	FC-2 CASE DRAIN FILTER STATIC SEAL LEAKING.	OLD SEAL. HAD PERMANENT SET.
1-30-85	COIL TUBE, SPOILER FC-1 PRESS. ROCKWELL P/N NONE	MISSION/ PROFILE	386HR (236 HR ON COIL TUBE)	LEAK AT FITTING SWAGE	PROBABLE FATIGUE CRACK IN TUBE IN FITTING SWAGE AREA. REPLACE WITH NEW ROCKWELL TUBE.
2-19-85	LOCK WASHER, RUDDER ACT'R, NAS513-12	MISSION/ PROFILE	422HR 1,416,900 CYC (PHASE II)	PISTON ROD CLEVIS LOCK WASHER FAILED. PISTON ROD BACKED OUT OF CLEVIS. LAST 5 THREADS IN CLEVIS STRIPPED. TANG BROKEN OFF TAB WASHER.	CLEVIS LOCKNUT WORKED LOOSE. FREE-PLAY AT TAB WASHER FAILED TANG DUE TO PISTON ROTATION. FAILED LOCKWASHER ALLOWED PISTON ROD TO UNSCREW FROM CLEVIS UNTIL REMAINING THREADS COULD NOT HOLD LOAD. COMPONENTS MUST BE SAFETY WIRED.
3-12-85	3-WAY SOL. VALVE, BENDIX P/N 3321473	PERFORMANCE CHECK	450HRS 900 CYC	NO FUNCTIONAL FAILURE. HIGH INTERNAL LEAKAGE.	DIAMETRAL SEAL NEAREST SOLENOID FAILED. BACKUP RING EXTRUDED AND O-RING RUPTURED. BACKUP RING WAS VIRGIN TEFLON AND SCARF CUT. RECOMMEND FILLED TEFON UN-CUT BACKUP.
3-13-85	4-WAY SOL. VALVE, BENDIX P/N 3321472	PERFORMANCE CHECK	450HR 6300 CYC (PHASE I & II)	NO FUNCTIONAL FAILURE. HIGH INTERNAL LEAKAGE.	DIAMETRAL SEAL NEAREST SOLENOID FAILED. BACKUP RING EXTRUDED AND O-RING RUPTURED. BACKUP RING WAS VIRGIN TEFLON AND SCARF CUT. RECOMMEND FILLED TEFLON UN-CUT BACKUP.
3-19-85	CHECK VALVE, FC-1 PUMP DISCH., CIRCLE SEAL P/N P4-858	MISSION/ PROFILE	452HR	PUMP MOTORING DURING SHUT-DOWN. POPPET STICKING OPEN.	SURFACE PITTING, FRETTING, OR EROSION ON VALVE BORE SURFACE. GUIDE RING SURFACE ROUGH. PROBABLE POPPET CHATTERING UNDER SOME OPERATING CONDITIONS. RECOMMEND STIFFER SPRING ON POPPET AND HARDER SURFACE ON VALVE BORE.
3-20-85	COIL TUBE, RFI FC-2 PRESS, VOUGHT P/N 83-00284-1	MISSION/ PROFILE	452HR 1,552,200 CYC	SEEPAGE AT FIXED END DEUTSCH FITTING.	TUBE FATIGUE CRACK INSIDE FITTING.

TABLE 35. (continued)

DATE	COMPONENT PART NO.	TEST	TIME OF FAILURE	FAILURE DESCRIPTION	PROBABLE CAUSE/RECOMMENDATIONS/ACTION
3-27-85	LH UHT ACT'R, VOUGHT P/N 83-00211-101	MISSION/ PROFILE	478HR 2,624,000 CYC (PHASE I & II)	LEAKAGE FROM BASE END SUPPORT.	CRACKS IN BASE END SUPPORT AT FILLET AREA AROUND BASE OF TONGUE. CAUSE: FATIGUE. ANALYSIS DETERMINED PART WAS UNDER-DESIGNED. INCREASE WALL THICKNESS BY 0.12". REQUIRE 32 FINISH IN FILLET AREA.
4-22-85	COIL TUBE FITTING, INBD. L.E. FLAP ACT'R #2 DEUTSCH P/N D11200TE-03	MISSION/ PROFILE	548HR 2740 CYC	LEAKAGE FROM SWAGE FITTING JOINT.	SUSPECT INCOMPLETE SWAGE. RE-SWAGING STOPPED LEAK. RECOMMEND USE OF RESISTOFLEX OR CRYOFIT FITTINGS. USE OF DEUTSCH FITTINGS ON 3/16 X .035 TITANIUM TUBING IS MARGINALLY SATISFACTORY.
5-1-85	COIL TUBE FITTING, INBD. L.E. FLAP ACT'R #1 DEUTSCH P/N D11200TE-03	MISSION/ PROFILE	584HR 2920 CYC	LEAKAGE FROM SWAGE FITTING JOINT.	SUSPECT INCOMPLETE SWAGE. RESWAGING STOPPED LEAK.

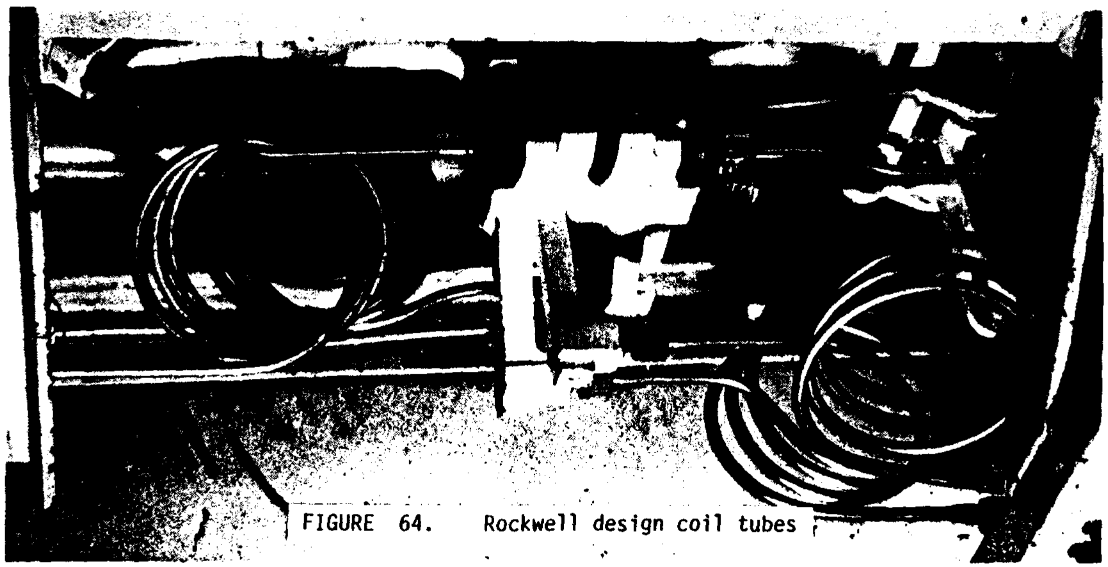

FIGURE 64. Rockwell design coil tubes

current MTBF. The principles of reliability growth development recognize this fact and provide an expression for determining current MTBF. Current (or instantaneous) MTBF is related to cumulative MTBF as follows:

$$\text{Current MTBF} = \frac{\text{Cumulative MTBF}}{1 - \alpha}$$

Where, α = slope of the line

The slope of the cumulative MTBF on Figure 65 is 0.162. Using the above equation, the current MTBF is found to be 94 hours. The current MTBF is shown on Figure 65 plotted as a line parallel to the cumulative MTBF.

A comparison with an operational hydraulic system was made using an analyzed sample of A-7E 3M data provided by Vought Corporation. The data were based on a 3.5 year period and 353,466 flight hours. Only those A-7E components that had equivalent counterparts on the LHS simulator were used to establish the A-7E MTBF base. A-7E pumps were not included since the 8000 psi pumps received special treatment during simulator testing, see section 4.5.2. The MTBF for an A-7E hydraulic system containing equipment equivalent to that tested on the LHS simulator is 76.3 hours. This is indicated by the horizontal line on Figure 65. The apparent improvement of the LHS MTBF over the A-7E 3000 psi system is 23%. This exceeds the 15% improvement goal set for the LHS Advanced Development Program and is approaching the 25% goal set for a production program.

7.3.3 Maintainability Assessment

A maintainability assessment based on laboratory test data is limited to a direct relationship to failure frequency (MTBF). Assuming a maintenance decrease proportional to the failure rate decrease, the reliability improvement predicted in section 7.3.2 will reduce maintenance man-hours by 18.8%. This exceeds the 15% improvement goal set for the LHS development program. Weight and volume reductions achieved by using 8000 psi components would facilitate access and handling in an A-7 aircraft and further improve maintainability.

The A-7E has pressure line and pump case drain filters; return line filters are not used. The LHS simulator has pressure, return, and case drain filters. The return filter was added to isolate contamination sources and provide a means for monitoring LHS pump health. LHS pressure and return filter element replacement intervals appeared to be normal. LHS pump case drain filter elements, however, required replacment after approximately 70 hours. Part of the problem was due to inadequate case drain filter size (-6) and the filtration level (5u). Use of a -8 size filter or a 15u filtration level would extend the element replacement

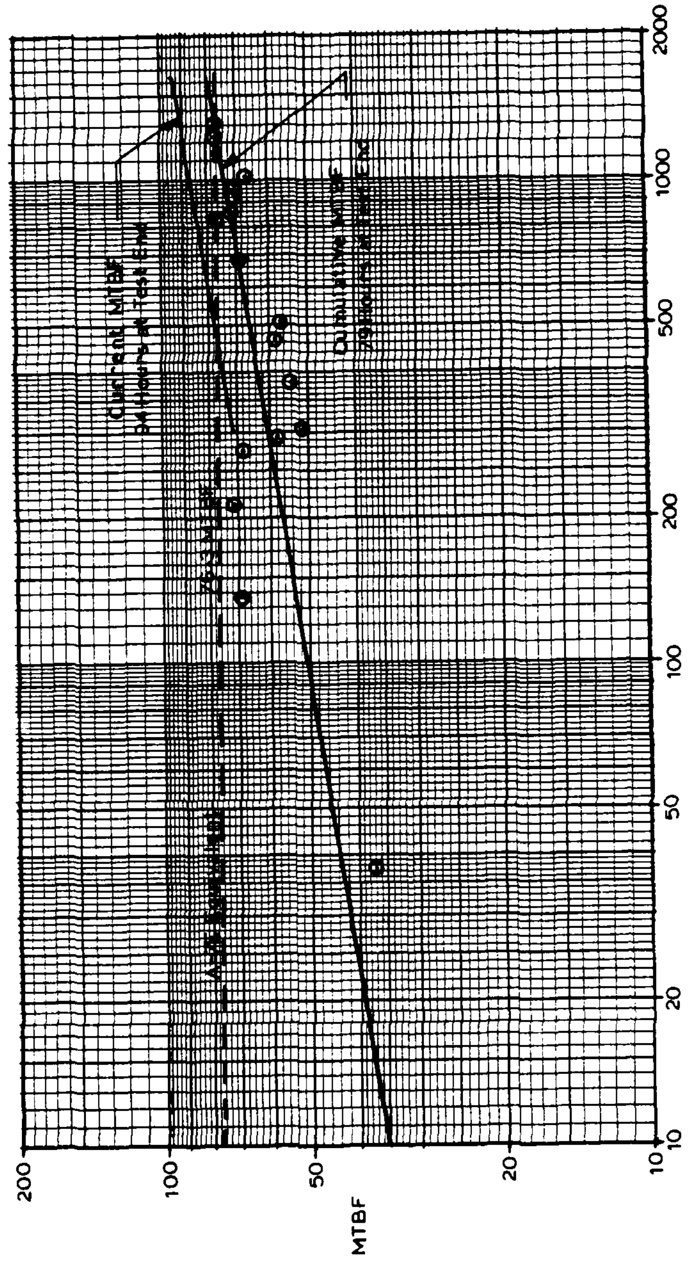

FIGURE 65. LHS simulator reliability growth

interval. Based on laboratory experience to date, return filters would probably be required in production lightweight hydraulic systems using the current pump design.

A concern that developed early in the LHS program was a black residue collected by system filters, reference 7. Although the substance was most prevalent in pump case drain filters, it was also observed in the pressure and return filters. Analyses were performed in an effort to determine the content and source of the residue. The residue appears to have no detrimental effect on LHS simulator operation except for filter element replacement (see section 4.5.3.7).

The use of coil tubing on the LHS simulator was originally conceived to eliminate the extension/rotary joints at the spoiler and RFI actuators. These 3000 psi joints had a history of leaking. Although seals developed during the LHS program would have probably reduced the leak frequency of such joints, coil tubing was believed to offer superior advantages. Reduced flow requirements at 8000 psi permitted the use of 3/16 O.D. tubing which in turn permitted coils to be made that would fit in retricted space areas. Coil tube failures were frequent, however, during simulator testing. Analyses clearly established the cause as fatigue in the tube at the fitting swage joint. Coil tubing is still considered a valid concept, but further development is required to provide satisfactory designs for the A-7E applicatons.

7.4. R&M CONCLUSIONS

The data base developed in this program substantiated that 8000 psi technology does not compromise the reliability or maintainabality of an aircraft hydraulic system. In fact, experience gained from LHS simulator testing indicates a potential improvement in reliability of 23% over a comparable 3000 psi system. The reduction in failure rates translates to an 18% reduction in maintenance man-hours.

The laboratory experience indicated a need for strict quality control during fabrication of components. Hardware built per design requirements was generally trouble-free.

The Phase II program should put an end to two common misconceptions concerning 8000 psi hydraulic systems: leaks and personnel safety. Leaks that occurred during the course of testing appeared as seepage, the same as occurs in 3000 psi systems. Leak frequency at 8000 psi was no different than at 3000 psi. Personnel safety is a concern with 3000 psi systems and rigid safety procedures must be followed when working around, performing maintenance on, or operating such systems. The procedures are no different for 8000 psi systems. Injuries that might be incurred as the result of personnel not taking proper safety precautions with 3000 psi systems could be serious; the same is true of 8000 psi systems.

8.0 LHS SPECIFICATIONS

8.1 INTRODUCTION

A total of 34 preliminary specifications covering system and component requirements for 8000 psi lightweight hydraulic systems were written in Phase I, reference 11. These documents were used in the procurement of components fabricated in Phase I and II. The specifications were submitted to the Navy in Phase I and are listed in Appendix G.

8.2 SPECIFICATION UPDATE

Test experience gained in Phase II provided information to update the LHS specifications. Changes were made in ten specifications covering:

- System Installation Requirements
- System Components
- Pumps
- Filters
- Cylinders
- Fittings
- Hoses
- Gland design
- Couplings
- Valves

The updated specifications are listed in Appendix G as "Rev. A". Technical changes in the specifications are identified with a vertical bar (line) in the left hand margin. The filter specification, LHS 8815, was editorially updated. One new specification was written covering titanium tubing, LHS-8842.

9.0 CONCLUSIONS

Conclusions presented in this section are based on experience gained from 600 hours of operating a full scale A-7E 8000 psi hydraulic system simulator. Four of 12 flight control actuators accumulated more than 3,000,000 cycles, and one pump was operated over 1,000 hours. The conclusions affirm that 1) 8000 psi hydraulic systems can be designed, fabricated, and operated for extended periods of time without special problems occurring; and 2) lightweight hydraulic systems offer important advantages.

SYSTEM WEIGHT AND SPACE SAVINGS

Weight savings achieved were 33.1%; the objective was 30%. Volume reduction attained was 36.3%; the goal was 40%. The weight of an aircraft hydraulic system designed to operate at 8000 psi would therefore be at least 30% less than the weight of an equivalent 3000 psi system; system volume would be at least 35% smaller. These are significant benefits.

RELIABILITY AND MAINTAINABILITY

The reliability and maintainability of an aircraft hydraulic system can be improved approximately 20% by operating at 8000 psi instead of 3000 psi; the objective was 15%. This important finding demonstrates the practicality of the lightweight hydraulic system concept.

SIMULATOR HARDWARE PERFORMANCE

System. The performance of 8000 psi systems using MIL-H-83282 fluid is equal to or better than comparable 3000 psi systems. Pressure dynamics are smaller percentage-wise; tubing vibration problems are thus minimized. Standing wave oscillating pressures and system transient pressures can be predicted with good accuracy by mathematical modeling. Fluid temperatures are acceptable and depend principally on pump heat rejection and control valve throttling losses. System internal leakage rates are a minor source of heat. Improvements in the current pump design and use of advanced actuator control techniques to reduce throttling losses could eliminate the need for heat exchangers.

Pumps. 8000 psi pumps can be designed to meet aircraft performance requirements. Pump ripple and response were exceptionally good. Pump wear characteristics were satisfactory except in the pintle bearing area. Heat rejection was higher than desired. Transfer tubes, used to transmit fluid from the cylinder block to the port plate, were a problem area. Pintle bearing wear and heat rejection could be improved in future 8000 psi pumps by more conservative design and by eliminating the transfer tubes.

Actuators. Conventional actuator design techniques are acceptable for use in 8000 psi systems. Actuator endurance characteristic are typical of those found in 3000 psi systems. Steel or titanium cylinders are recommended for primary flight control actuators; aluminum can be used for secondary flight controls and utility actuators. Control valve null leakage of 125 cc/min maximum is readily attained. Several problems encountered were due to out-of-tolerance dimensions which emphasized the need for strict quality control during fabrication of hardware.

Seals. Use of standard sealing concepts with tighter tolerances to reduce extrusion gaps proved very successful.

Dynamic Seals

Piston Rod	Two-stage unvented seals performed satisfactorily.
Piston Head	Off-the-shelf piston seals were used successfully.

Static Seals

Diametral	Standard MIL-G-5514 type seals were satisfactory.
Rosan	Rosan fitting seals were satisfactory.
Boss	Standard MS33649 boss seals performed satisfactorily when the boss was steel or titanium. Aluminum bosses are not recommended for use at 8000 psi.

Fittings. Internally swaged and shrink-fit type fittings are satisfactory at 8000 psi. Externally swaged fittings are also satisfactory except re-design of the -3 size is required. Improvement in tooling life for -3 size internally swaged fittings is recommended.

Hoses. Hose with wire braid performed satisfactorily. Kevlar braid hoses will require additional development effort to eliminate fluid seepage through the hose wall and to improve fitting attachment integrity.

Coil Tubing. Coil tubing has important potential use in 8000 psi systems. Standard configurations will perform satisfactorily. Failures encountered during simulator endurance testing were the result of space constraints unique to the A-7E airplane design and to leakage at -3 size externally swaged fittings (see Fittings). All failures were in the fitting/tube swage area; no failures occurred in the tube coils.

Filters. A 5u filtration level is recommended for 8000 psi systems because of small clearances in some component parts. The dirt holding capacity of 8000 psi filters must be larger than 3000 psi filters (for the same tube size) because of higher flow rate allowables in 8000 psi systems.

Fluid Contamination. A fluid cleanliness level of NAS 1638, Class 8 is easily achieved using 5u filtration. A black residue collected on patches made of filter bowl debris was considered to be the result of normal wear on system components. The residue had no harmful effect on component performance, and was also found to occur in the 2300 psi load system of the simulator.

Valves, Restrictors. Check valves, relief valves, solenoid valves, and restrictors can be readily designed for use at 8000 psi.

GSE. Conversion of 3000 psi GSE to 8000 psi GSE can be achieved without difficulty. Care should be exercised during design to consider total system heat generation and avoid the need for an oversize heat exchanger. An 8000 psi pump designed specifically to match system flow requirements is recommended to minimize heat rejection. (The current pump is de-stroked 60%.)

10.0 RECOMMENDATIONS

The LHS advanced development program should proceed by conducting the planned Phase III flight tests using an A-7E test bed aircraft. 8000 psi technology is maturing, and a successful flight test program would fully demonstrate its capabilities and benefits.

Additional effort should be directed toward support of 8000 psi technology for next generation aircraft. Recommended tasks are:

- Use the LHS simulator as a means to evaluate emerging technologies such as composite actuators, rotary actuators, PEEK seals, and energy efficient concepts.
- Conduct full qualification tests on 8000 psi tubing/fittings. Pursue re-design of -3 size externally swaged fittings and internal swage tooling.
- Develop coil tube installation design concepts, guidelines, and limitations.
- Conduct extreme temperature tests (-40 to +275°F) on LHS simulator modules and components.
- Conduct full qualification of an LHS pump refined by a conservative design approach and elimination of transfer tubes.
- Develop a multiple pressure level pump to reduce system power consumption.
- Pursue acquisition/development of a GSE pump sized to match 8 gpm flow requirements.

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12.0 LIST OF ABBREVIATIONS

A/C	aircraft
AFCS	automatic flight control system
AIL	aileron
B/H	bulkhead half
BTU/min	British Thermal Units per minute
B-U	back-up ring
C/D	center dam
CIPR	cubic inches per revolution
CGT	capped GT seal (Greene, Tweed)
cpm	cycles per minute
CGTL	capped GTL seal (Greene, Tweed)
CRES	corrosion resistant
D-D	Double-Delta seal (Shamban)
E-C	Ener-cap seal (Greene, Tweed)
EPP	emergency power package
FC-1	flight control system #1
FMEA	failure-modes-and-effects analysis
gal	gallon
gpm	gallons per minute
GSE	ground support equipment
H/H	hose half
Hp	horsepower
Hr	hour
H-S	Hat Seal (Shamban)

Hz	Hertz (cycles per second)
in.	inch
in^3	cubic inches
inbd.	inboard
lb	pound
IS	instant spectrum
IT	instant time
L.E.	leading edge
LH, L/H	left hand
LHS	lightweight hydraulic system
max.	maximum
MFHBF	mean flight hours between failures
M/N	model number
min	minute (time)
MMH/FH	maintenance man-hours per flight hour
N.A.	not applicable
NAAO	North American Aircraft Operations
NADC	Naval Air Development Center
NAS	National Aerospace Standard
No.	number
O.D.	outside diameter
O-R	O-ring
O/S	outside
outbd.	outboard
Δp	differential pressure

PC-1	power control system #1
PEEK	polyether etherketone
P/H	pump half
P/N	part number
P-P	peak-to-peak
psi	pounds per square inch
psig	pounds per square inch gage pressure
PWM	pulse width modulation
QD	quick disconnect
RAT	ram air turbine
RFI	roll feel isolation
RH, R/H	right hand
R&M	reliability and maintainability
rpm	revolutions per minute
+S	plus seal (Shamban)
SARDIP	Stricken Aircraft Reclamation and Disposal Program
sec	second (time)
S/N	serial number
sys.	system
T.E.	trailing edge
TRAF	Trapezoidal Seal (Greene, Tweed)
T-S	Tee Seal (Greene, Tweed)
u	micron
UHT	unit horizontal tail

APPENDIX A

MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
3-1-83	0	0	FC-1&2	AILERON ACTUATOR	83-00221	BEGIN MISSION/PROFILE CYCLING. ONE PUMP/ONE SYSTEM. NO AILERON ACTUATOR DUE TO PISTON SEAL PROBLEM
3-2-83	2					RUDDER & UHT ACT'RS DISASSEMBLED. PISTON SEALS WITH METAL BACKUPS TO BE REPLACED. CYCLING HELD UP 'TIL NEW SEALS ARRIVE.
4-7-83	2					RESUME CYCLING. NEW PISTON SEALS IN UHT & RUDDER ACTUATORS. PWM FIBER OPTICS INSTALLED TO CONTROL RUDDER AFCS ACTUATOR.
4-12-83	14	27,000	FC-1	O-RING	MS28778-4	LEAK AT RUDDER AFCS 3-WAY SOL. VALVE. FITTING WAS LOOSE. REPLACE O-RING. TIGHTEN FITTING.
4-18-83	28					INSTALL AILERON ACTUATOR IN SIMULATOR. FC-2 PLUMBED IN. FC-1 INOPERATIVE DUE TO INABILITY TO REPAIR FC-1 CYLINDER BORE.
4-22-83	50	168,700	FC-1	PUMP	PV3-047-2	SEND PUMP TO VICKERS FOR TEAR DOWN AND WEAR INSPECTION.
5-4-83	50					RESUME CYCLING WITH FC-1 PUMP.
5-9-83	62	96,800	FC-2	COIL TUBE	83-00288-3	SPOILER ACTUATOR R2 COIL TUBE LEAKING 7 DROPS/CYCLE.
5-12-83	72	103,500	FC-2	COIL TUBE	83-00288-3	SPOILER R2 COIL TUBE LEAKING 0.7CC/CYCLE.
5-23-83	78	78HR	FC-1	PUMP CASE DRAIN FILTER ELEMENT	AC-7031-697Y6 (M8815/18-1)	FILTER ΔP BUTTON OPERATING PERIODICALLY. REPLACE ELEMENT. (5 MICRON)
5-24-83	84	111,300	FC-2	COIL TUBE	83-00288-3	SPOILER R2 COIL TUBE FAILED. LOST APPROX 1 GAL OF SYSTEM FLUID. REPLACE TUBE WITH -3 SIZE HOSE.
6-2-83	100	337,300	FC-1	PUMP	PV3-047-2	SEND PUMP TO VICKERS FOR TEAR DOWN AND WEAR INSPECTION.
6-23-83	100					RESUME CYCLING WITH FC-1 PUMP. INSTALL NEW 5 MICRON ELEMENT IN PUMP CASE DRAIN FILTER.
6-24-83	108	108HR	FC-1	CHECK VALVE	P1-858	CHECK VALVE LEAKING 4 DROPS/MIN. WRONG SIZE BACKUP RING IN VALVE. REPLACE O-RING. VALVE IN SPEED BRAKE CIRCUIT.

MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
6-27-83	112	130,500	FC-1	COIL TUBE	83-00287-1	SPOILER P1 COIL TUBE LEAKING 11 DROPS/MIN. REPLACE TUBE WITH -3 SIZE HOSE.
8-2-83	138		FC-1	COIL TUBE	83-00287-1	REPAIR SPOILER P1 COIL TUBE WITH CRYOFIT FITTINGS. INSTALL P1 COIL TUBE ON SPOILER ACTUATOR.
8-2-83	138	138	FC-1	QUICK DISCONNECT	3305-6	PUMP CASE DRAIN QD LEAKING. QD OLD LAB PART USED IN PHASE I. REPLACE WITH NEW QD.
8-5-83	150	506,000	FC-1	PUMP	PV3-047-2	SEND PUMP TO VICKERS FOR TEAR DOWN AND WEAR INSPECTION. SHUT DOWN FOR COMPONENT PERFORMANCE CHECKS & ACTUATOR SEAL INSPECTION.
10-5-83	---	---	---	SOLENOID VALVE	3321472 3321473	END CAP P/N 3321846 BLEW OFF AT 26,000 CYCLES DURING TEST AT GRUMANN. FAILURE DUE TO STRESS RISER. NEW CAPS WITH LARGER FILLET INSTALLED AS PRECAUTION.
1-11-84	150		FC-1	RESTRICTOR	JEFX0483000A	2 GPM RESTRICTOR INSTALLED IN INLET PORT OF RUDDER AFCS ACTUATOR 3-WAY SOLENOID VALVE TO ELIMINATE PRESSURE SURGE IN ACTUATOR PRESSURE LINE.
1-23-84	150	0	FC-1	FILTER ELEMENT	AC-9607F-6	RESUME MISSION/PROFILE CYCLING USING "SPARE" PUMP. INSTALL NEW 15 MICRON ELEMENT IN PUMP CASE DRAIN FILTER.
1-23-84	150	151,000	FC-2	COIL TUBE	83-00288-1	SPOILER ACTUATOR P2 LEAKING 60 DROPS/MIN. REPLACE TUBE WITH -3 SIZE HOSE.
1-31-84	170	0		COIL TUBE	NONE	INSTALL ROCKWELL STEEL COIL TUBES AT SPOILER ACTUATOR P1 AND R2 PORTS.
2-1-84	172	1,160,000	FC-2	O-RING	MS28778-4	O-RING ON CONTROL VALVE #3 CYLINDER PORT BLEW (RUDDER ACTUATOR). FITTING WORKED LOOSE. REPLACE O-RING.
2-7-84	190	190HR	FC-1	O-RING	MS28778-5	O-RING ON -5 END PORT IN PRESSURE MANIFOLD LEAKING. REPLACE O-RING.
2-9-84	200	674,700	FC-1	PUMP	PV3-047-2	SEND PUMP TO VICKERS FOR TEAR DOWN AND WEAR INSPECTION AND INSTALLATION OF LARGER PINTLE BEARINGS.
2-17-84	---					INSTALL ROCKWELL TI COIL TUBES AT P1, R1, P2, R2 ON SPOILER ACTUATOR. PUT NEW PIN IN LOAD CYL. CLEVIS IN SPOILER MODULE. REPLACE RET. FILTER WITH APM FILTER WITH ΔP BUTTON.

MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
2-22-84	200					RESUME MISSION/PROFILE CYCLING USING FC-1 PUMP.
2-27-84	212	212HR	FC-1	O-RING	MS28778-6	LEAK AT PUMP CASE DRAIN BOSS SEAL (LOW PRESSURE). REPLACE O-RING.
3-5-84	242	163,000		SPOILER MODULE		SPOILER LOWER LH HINGE FAILED (PART PREVIOUSLY SUBJECTED TO STATIC TESTS AT VOUGHT). MISSION/PROFILE CYCLING TO CONTINUE WITHOUT SPOILER ACTUATOR.
3-6-84	250	743,400	FC-1	PUMP	PV3-047-2	SEND PUMP TO VICKERS FOR TEAR DOWN AND WEAR INSPECTION.
3-12-84	---		FC-1	FILTER ELEMENT	AC-7031F-697Y6 (M8815/18-1)	NEW SPOILER ASSY INSTALLED IN SPOILER MODULE. PUMP CASE DRAIN LINE RE-ROUTED DIRECTLY TO RESERVOIR. INSTALL NEW 5 MICRON ELEMENT.
3-13-84	250					RESUME MISSION/PROFILE CYCLING WITH FC-1 PUMP (NEW PINTLE BEARINGS INSTALLED)
3-14-84	254	254HR	FC-1&2	O-RING	MS28778-4	LOCATION: P1, C1, C2 BOSS PORTS ON RUDDER ACT'R CONTROL VALVE. HOUSING (ALUMINUM) STRETCH IN PORT THDS. ALLOWS O-RING PINCHING CAUSING DEBRIS. REPLACE O-RINGS.
3-19-84	272	272HR	FC-1	RELIEF VALVE	A-63256-3 215-32359-3	RESERVOIR LOW PRESSURE RELIEF VALVE LEAKING 2.5 CC DURING 5 MIN. SPEED BRAKE CYCLING. REPLACE FC-1 VALVE WITH FC-2 VALVE.
3-27-84	300					SHUT DOWN FOR COMPONENT PERFORMANCE CHECKS & ACTUATOR SEAL INSP. SIMULATOR DOWN FOR FABRICATION OF FC-2 HYDRAULIC SYSTEM.
6-25-84	---	0	FC-1&2	RH UHT ACTUATOR	83-00211-102	ACT'R DISASSEMBLED TO INSTALL NEW PISTON SEALS. FOUND SCORING, CORROSION & OUT-OF-TOLERANCE DIMENSIONS. RE-GRIND PISTON ROD. CYLINDER BORES NOT RE-WORKED.
8-1-84	---	0	FC-2	RH UHT ACTUATOR ROD SEAL	S30650-217-14	CENTER DAM SEAL FOUND TO BE INSTALLED IMPROPERLY AND DAMAGED. REPLACE WITH GREENE, TWEED P/N 591-21700-160-0190.
10-8-84	300					RESUME MISSION/PROFILE CYCLING. TWO PUMP, TWO SYSTEM OPERATION. RH UHT ACT'R AND RH WING SEAL TEST FIXTURE INSTALLED. BOTH PUMPS HAVE "LARGER" PINTLE BEARINGS WITH CROWNED ROLLERS. SIMULATOR CYCLING PROGRAM REVISED. SEALS IN RH UHT ACT'R REPLACED.

MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
10-11-84	304	4HR	FC-2	RELIEF VALVE	A-63256-3 215-32359-3	RESERVOIR LOW PRESSURE RELIEF VALVE OPENED. APPROX 1 GAL. OF SYSTEM FLUID LOST. VALVE DISASSEMBLED AND ADJUSTED FOR HIGHER SETTING.
10-17-84	310	34,000	FC-1&2	RH UHT ACT'R	83-00211-102	ACT'R PISTON NOT MOVING PROPERLY WITH 2% INPUTS. REMOVE ACT'R TO DETERMINE CAUSE AND FIX. CONTINUE CYCLING WITHOUT RH UHT ACT'R.
10-17-84	310	1,073,200	FC-2	COIL TUBE	83-00283-1	RFI P1 TUBE LEAKING AT DEUTSCH FITTING. REPLACE P1 and R1 TUBES WITH ROCKWELL DESIGN COIL TUBES.
11-2-84	311	1,100,000+ PHASE I	FC-1&2	LH UHT ACT'R	83-00211-101	ACT'R RUNNING ROUGH. INPUT SHAFT HAS -208 SIZE (NON-STD.)O-RING. REPLACE IT WITH TWO O-RINGS -018 & -114 TO REDUCE SQUEEZE ON SHAFT.
11-26-84	339	489HR	FC-1	CHECK VALVE	95201-5	SLIGHT EXTERNAL LEAKAGE. POPPET FAILED. REPLACE VALVE WITH *CIRCLE SEAL P/N P4-858.* VALVE 30" FROM PUMP.
12-4-84	342	42HR	FC-2	FILTER ELEMENT	AC-7031F-697Y6	PUMP CASE DRAIN FILTER ΔP INDICATOR OPERATED. INSTALL NEW ELEMENT. REMOVE FC-2 PUMP S/N 346580 (SPARE). REPLACE WITH S/N 346168 (FC-2).
12-11-84	354		FC-1&2	RH UHT ACT'R	83-00211-102	RE-INSTALL ACTUATOR INPUT SHAFT. BALL CHROME PLATED TO REDUCE FREE-PLAY BETWEEN BALL AND SPOOL SLOT.
12-13-84	360		FC-2	PUMP	PV3-047-2	"SPARE" PUMP S/N 346580 RECEIVED FROM VICKERS AND INSTALLED ON FC-2 PAD.
12-17-84	362	62HR	FC-2	PUMP HOSE	DE6356-102-0300	HOSE LEAKS AROUND SWAGED END NEAR PUMP. HOSE REPLACED WITH TITEFLEX P/N F37404008-0300.
1-2-85	372	1,254,900+ PHASE I	FC-1&2	LH UHT ACT'R	83-00211-101	ACTUATOR RUNNING ROUGH. REMOVE ACTUATOR FOR FIX.
1-24-85	372		FC-1&2	LH UHT ACT'R	83-00211-101	RE-INSTALL ACTUATOR. INPUT SHAFT NICKEL PLATED AND HOUSING GROOVE MACHINED TO ACCEPT -115 SIZE O-RING.
1-25-85	376		FC-1&2	LH UHT ACT'R	83-00211-101	ACTUATOR RUNNING ROUGH. REMOVE FOR FIX. CONTINUE CYCLING WITHOUT LH UHT ACT'R
1-28-85	380	530+	FC-2	O-RING	28775-028	CASE DRAIN FILTER STATIC SEAL LEAKING. SEAL HAS PERMANENT SET. REPLACE O-RING.

MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
1-30-85	386		FC-1	COIL TUBE	NONE	ROCKWELL DESIGN COIL TUBE ON SPOILER P-1 LEAKING AT FITTING. REPLACE TUBE WITH ANOTHER ROCKWELL TUBE.
2-1-85	392		FC-1&2	LH UHT ACT'R	83-00211-101	RE-INSTALL ACTUATOR. 0.0001 IN. REMOVED FROM CENTER LAND DIA. ON CONTROL SPOOL. REMOVE 0.004 IN. FROM NICKEL PLATED SHAFT.
2-5-85	400	420,500	FC-2	SEAL TEST FIXTURE		ROD SEALS LEAKING EXCESSIVELY. REMOVE FC-2 FIXTURE. CONTINUE CYCLING WITHOUT IT. PROPER SEALS NOT AVAILABLE.
2-19-85	422	1,416,900+ PHASE I	FC-1&2	LOCK WASHER	NAS513-12	THREADS STRIPPED OUT OF CLEVIS. LOCK WASHER FAILED. CONTINUE CYCLING WITHOUT RUDDER ACT'R.
2-21-85	432	0	FC-1&2	RUDDER ACT'R CLEVIS	CV15-151567-1	RECEIVE NEW CLEVIS FROM VOUGHT. ALSO RECEIVE NEW LOCK WASHER. RESUME CYCLING RUDDER ACTUATOR.
2-26-85	450					3RD BLOCK OF 150 HRS. COMPLETED. SHUT DOWN FOR COMPONENT PERFORMANCE CHECKS & ACTUATOR SEAL INSPECTIONS.
3-12-85	450	900	FC-1	3-WAY SOL. VALVE	3321473	PERF. TEST DISCLOSED HIGH INTERNAL LEAKAGE. INTERNAL DIAMETRAL SEAL FAILED. REPLACE O-RING MS28775-007.
3-13-85	450	6,300	FC-1	4-WAY SOL. VALVE	3321472	PERF. TEST DISCLOSED HIGH INTERNAL LEAKAGE. INTERNAL DIAMETRAL SEAL FAILED. REPLACE O-RING MS28775-007.
3-14-85			FC-1	3-WAY SOL. VALVE	306750-1001	3-WAY VALVE 3321473 PUT IN LOAD SYSTEM AT PITCH AFCS ACT'R. 3-WAY VALVE 306750-1001 INSTALLED IN FC-1 AT YAW AFCS ACT'R.
3-15-85	450					MISSION/PROFILE CYCLING RESUMED.
3-19-85	452	452HR	FC-1	CHECK VALVE	P4-858	POPPET STICKING, ALLOWING PUMP TO MOTOR DURING SHUT DOWN. POLISH VALVE BORE AND POPPET. REINSTALL VALVE.
3-20-85	452	1,552,200	FC-2	COIL TUBE	83-00284-1	RFI ACT'R P2 TUBE LEAKING AT FITTING. REPLACE P2 AND R2 TRI-COILS WITH -3 HOSES.

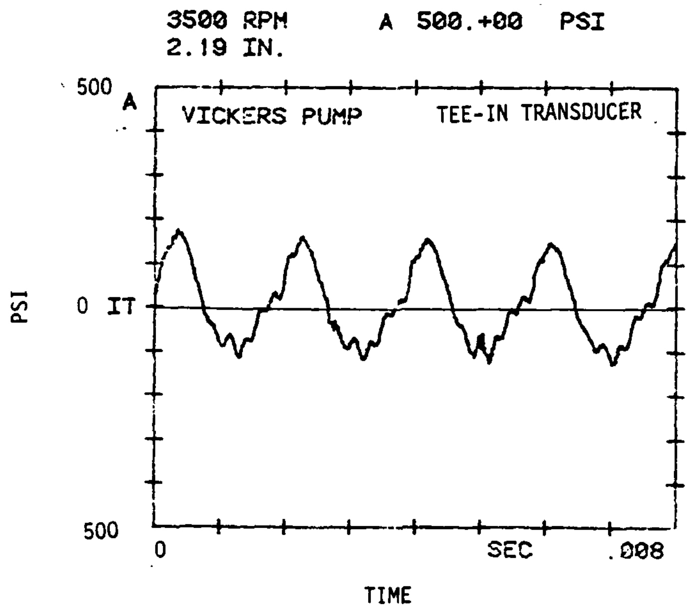
MISSION/PROFILE TEST LOG

DATE	SIMULATOR HOURS	COMPONENT CYCLES/HOURS	SYSTEM	COMPONENT	PART NO.	REMARKS
3-21-85	460		FC-2	PUMP	√3-047-2	PATCH ON FC-2 FILTER HAD EXCESSIVE WEAR DEBRIS. REMOVE PUMP 346580 AND REPLACE IT WITH 346168. PUMP 356480 SHIPPED TO VICKERS.
3-21-85	460	210HR 160HR	FC-1 FC-2	FILTER ELEMENT	AC-9607F-6	INSTALL NEW 15u ELEMENTS IN FC-1 & FC-2 PUMP CASE DRAIN FILTERS.
3-27-85	478	2,624,000 (PH. I & II)	FC-1&2	LH UHT ACT'R	83-00211-101	CRACK IN BASE END SUPPORT FITTING P/N 83-00214-101. REMOVE ACTUATOR. CONTINUE CYCLING WITHOUT LH UHT ACTUATOR.
3-29-85	484			RH UHT ACT'R	83-00211-102	REMOVE RH UHT ACT'R. REMOVE BASE END SUPPORT FITTING AND INSTALL IT IN LH UHT ACT'R. RESUME CYCLING WITHOUT RH UHT ACT'R.
4-2-85	493	0	FC-1&2	HOSE	28404003	REMOVE P1 & P2 COIL TUBES ON SPOILER ACT'R. REPLACE TUBES WITH DONATED -3 HOSES. ALSO INSTALL -3 HOSE AT FC-1 SEAL TEST FIXTURE.
4-18-85	544		FC-1	RESTRICTOR	JEFX0483000A	DISCOVER CAUSE OF YAW AFCS 3-WAY SOL. VALVE MALFUNCTION IS LOCATION OF RESTRICTOR. RELOCATE RESTRICTOR FROM PORT P TO PORT C ON VALVE.
4-19-85	544	0	FC-1&2	SUPPORT FITTING	83-00214-101A	NEW BASE END SUPPORT FITTINGS WITH HEAVIER WALL FABRICATED. NEW FITTING INSTALLED IN LH & RH UHT ACTUATORS. BOTH ACTUATORS RUNNING.
4-22-85	548	2,740	FC-2	COIL TUBE FITTING, ACT'R #2	D11200TE-03	DEUTSCH FITTING ON COIL TUBE ON INBOARD L.E. FLAP EXTEND PORT LEAKING DURING OPERATION APPROX. 3 DROPS.
4-24-85	558		--	UHT LOAD MODULE	TL13197	UHT ACTUATOR BASE END SUPPORT BOLT FAILED. BOLT IS ONE OF SIX. FATIGUE CAUSED FAILURE. REPLACE BOLT.
4-25-85	560	260HR	FC-2	RETURN FILTER	AC-7031-1097Y6 (M8815/6-10)	140 PSI ΔP ACROSS ELEMENT. REPLACE ELEMENT. FC-1 RETURN FILTER ΔP IS 40 PSI (OK).
5-1-85	584	2,920	FC-2	COIL TUBE FITTING, ACT'R #1	D11200TE-03	DEUTSCH FITTING ON INBOARD-INBOARD L.E. FLAP ACTUATOR COIL TUBE LEAKING 26 DROPS/MIN. OUTBOARD COIL TUBE FITTING LEAKING 2 DROPS/MIN.
5-3-85	590	590	FC-1	O-RING	MS28778-8	PUMP CASE DRAIN LINE INSTRUMENTATION CROSS O-RING LEAKING. O-RING HARD. REPLACE O-RING.
5-6-85	600					4TH BLOCK OF 150 HRS COMPLETED. SHUT DOWN TO RUN COMPONENT PERFORMANCE CHECKS AND EXAMINE ACTUATORS FOR WEAR.

APPENDIX B

PRESSURE RIPPLE DYNAMICS DATA

NOTE: The Abex pump data presented on pages 170 through 175 are given for information purposes only. The Abex pump (M/N AP6V-57) was temporarily installed in FC-1 system in place of the LHS pump (Vickers M/N PV3-047-2) to provide comparison data. See reference 3 for Abex pump details.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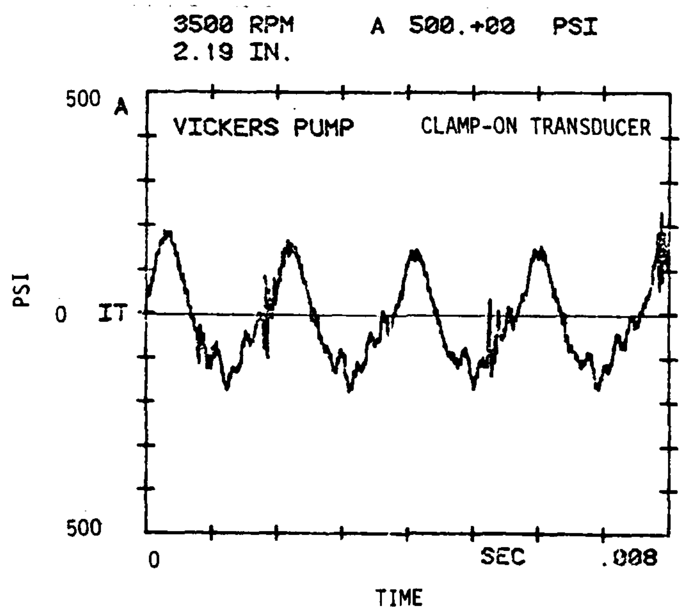
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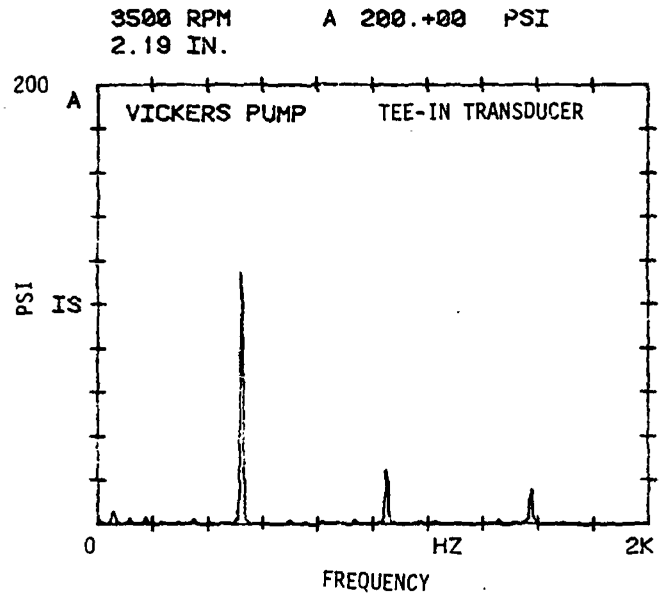
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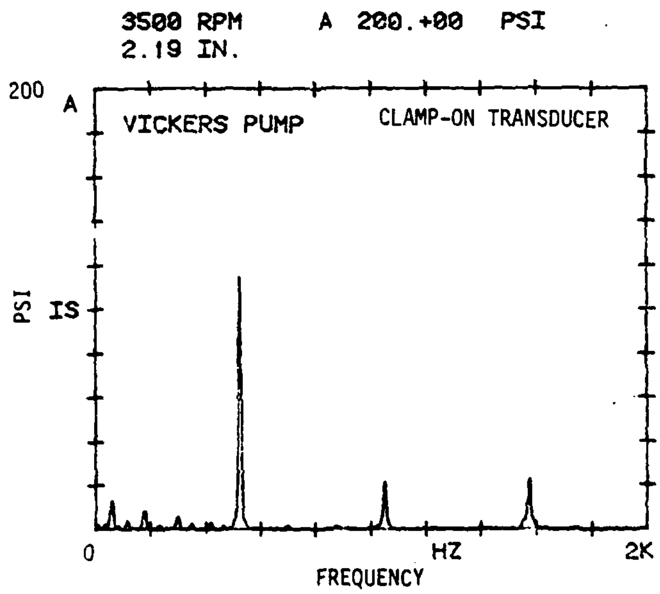
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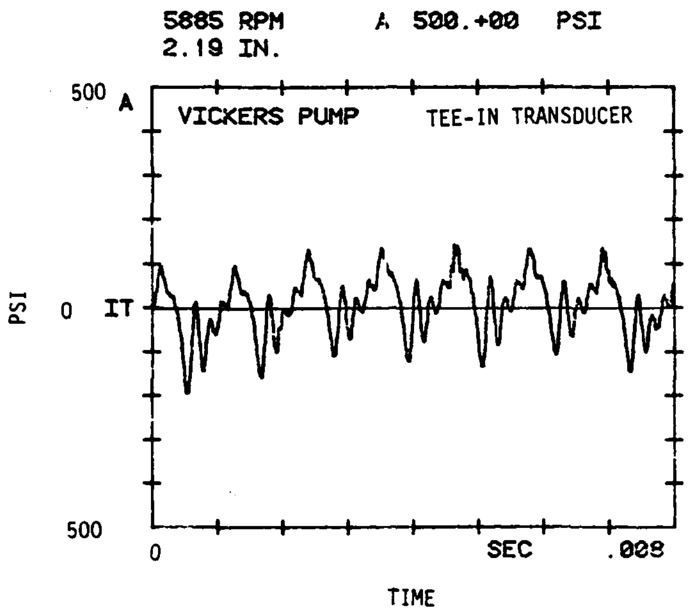
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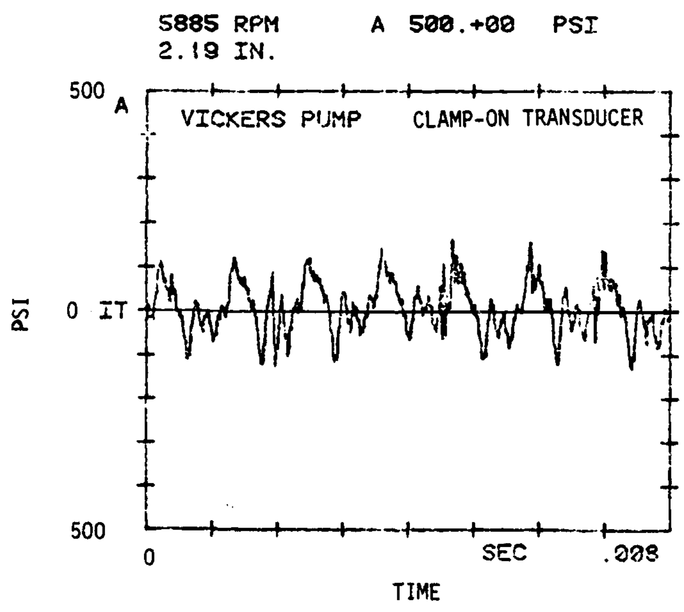
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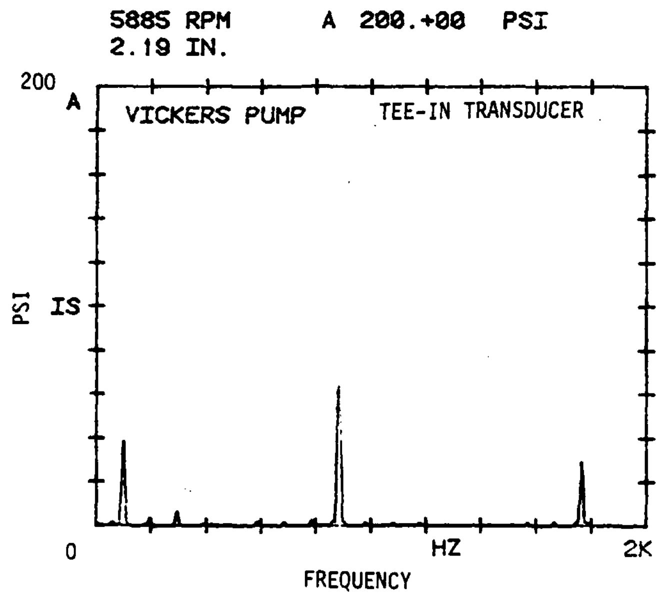
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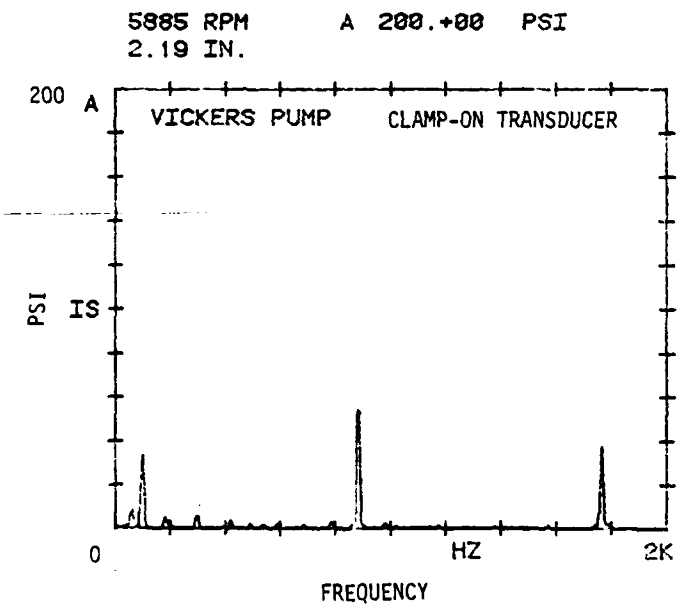
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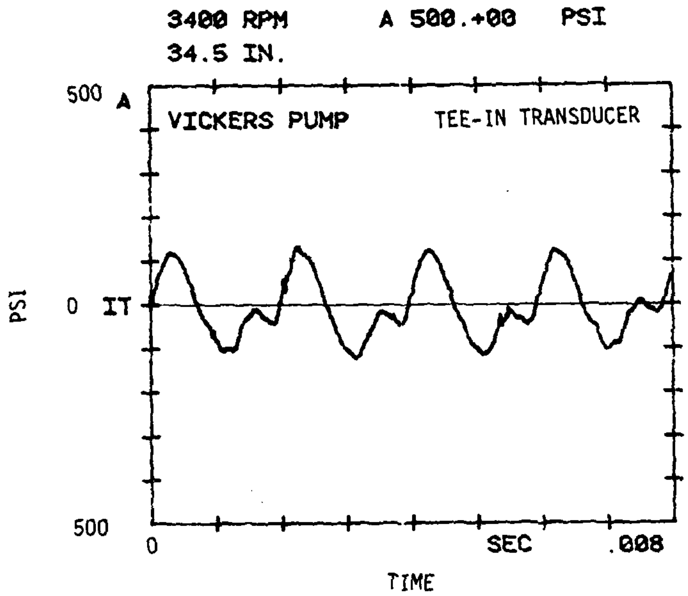
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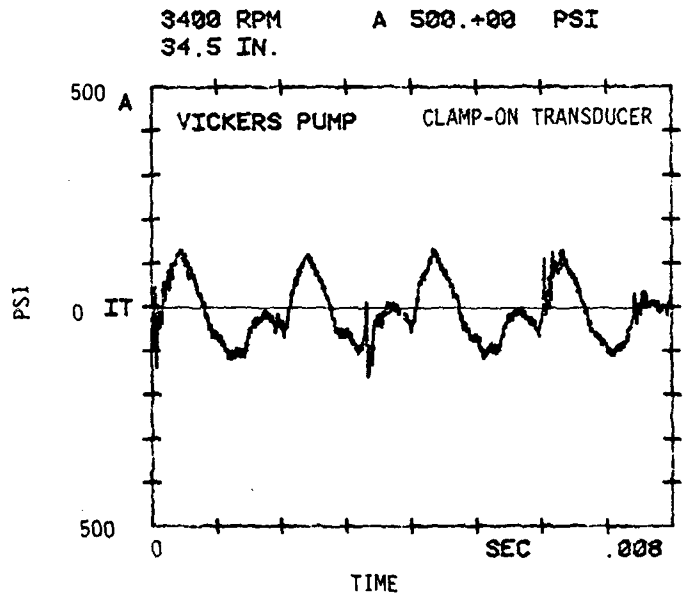
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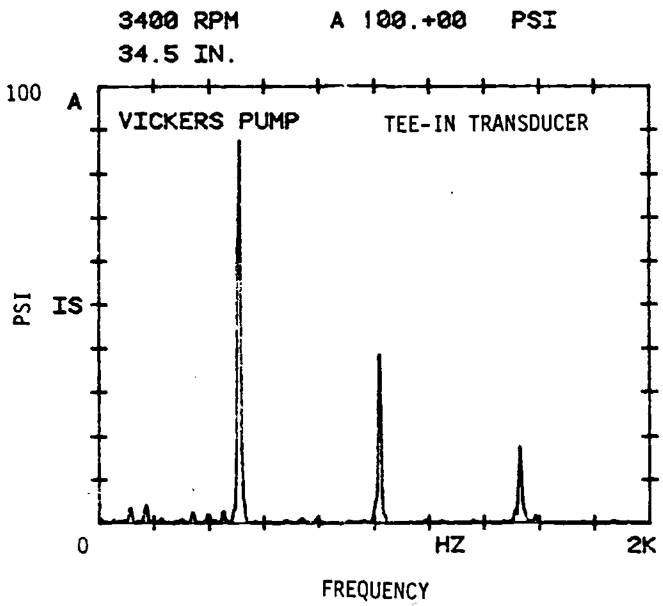
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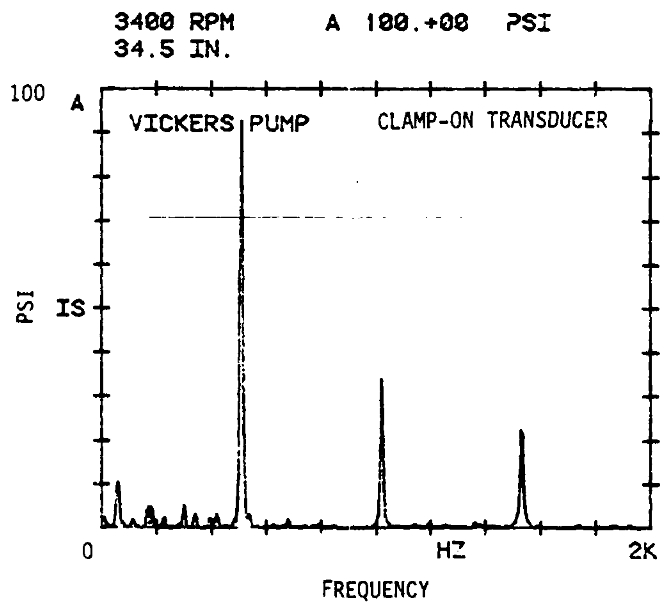
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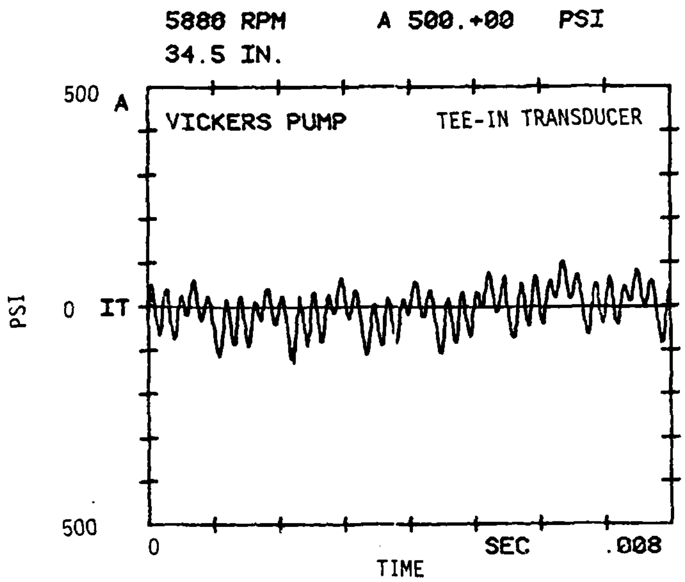
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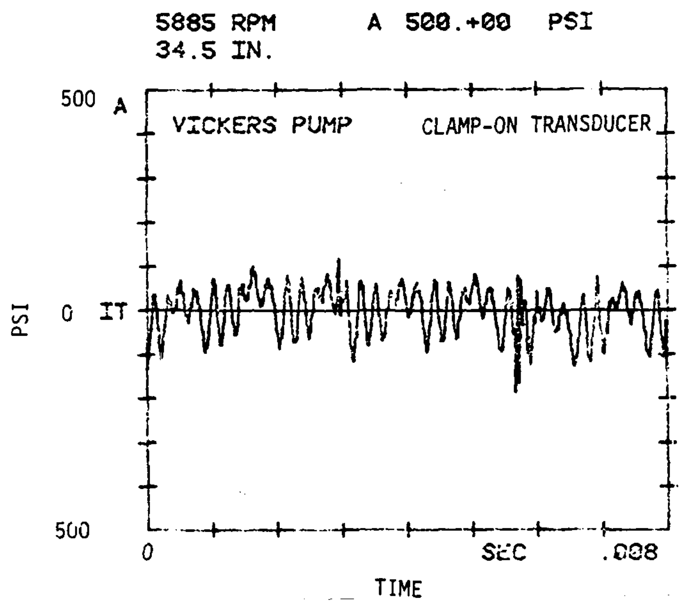
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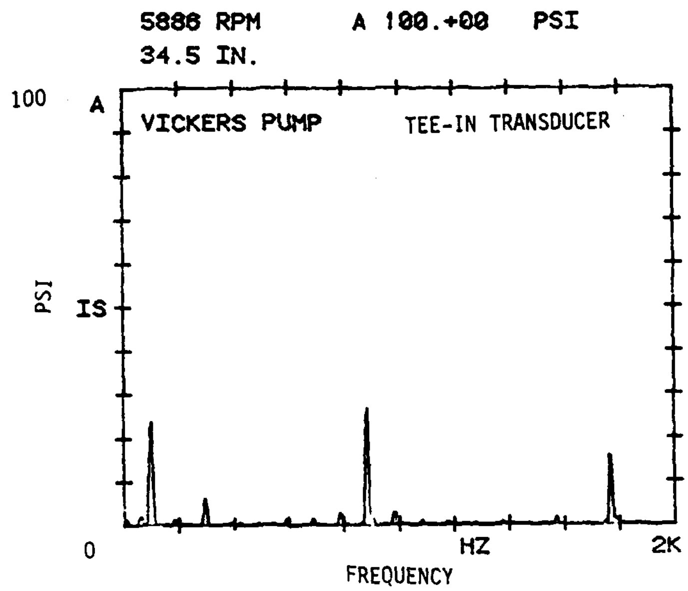
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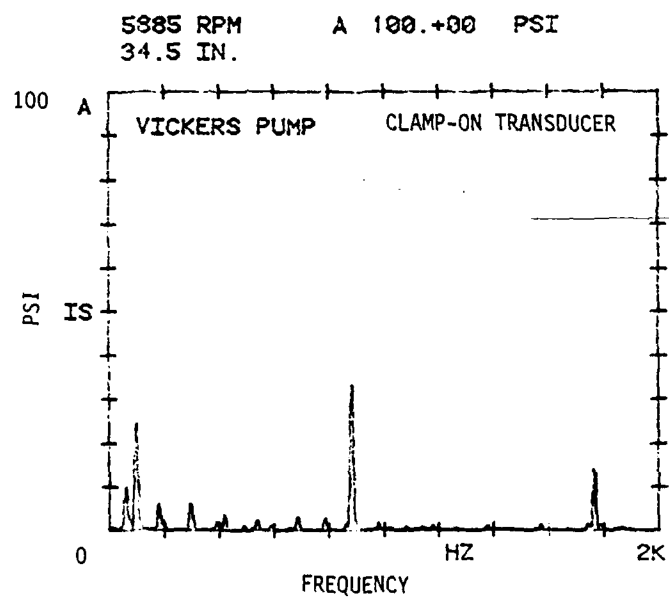
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34.5 IN.
100
A
VICKERS PUMP
CLAMP-ON TRANSDUCER
PSI
IS
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HZ
2K
FREQUENCY

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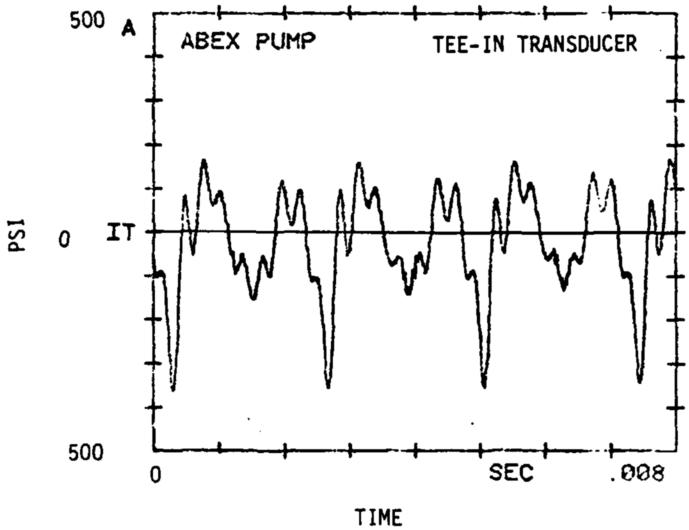
2.19 IN.



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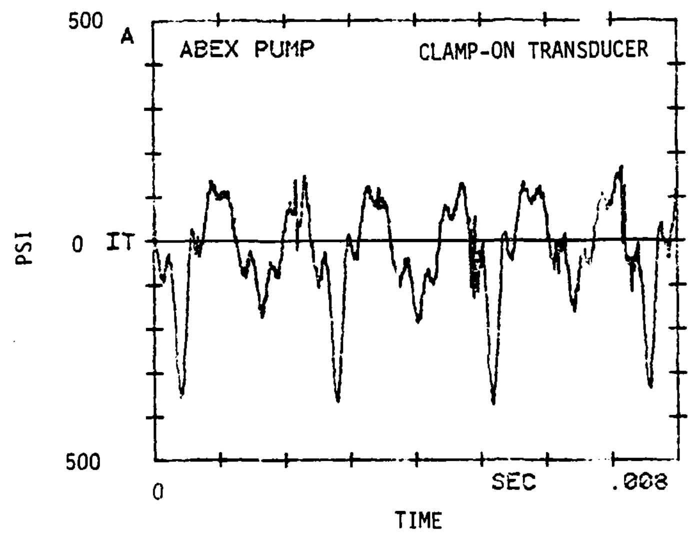

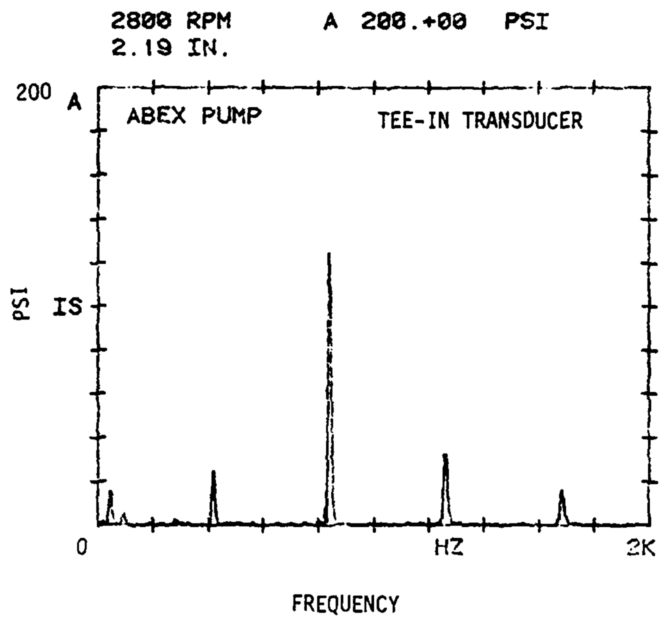
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A
ABEX PUMP
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PSI
IS
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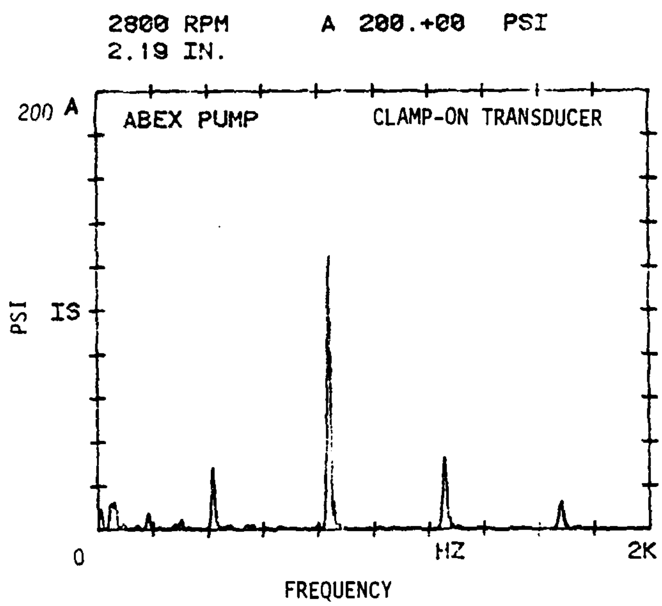
HZ
2K
FREQUENCY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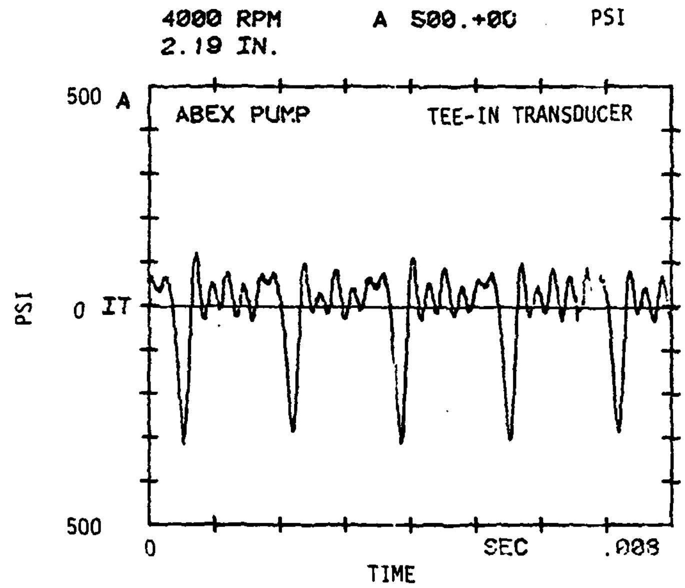
2.19 IN.
200
A
ABEX PUMP
CLAMP-ON TRANSDUCER
PSI
IS
0
HZ
2K
FREQUENCY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2.19 IN.
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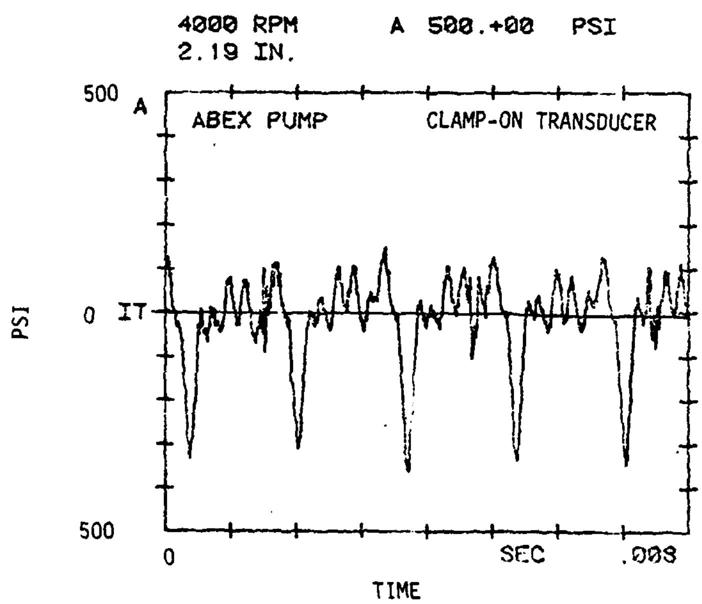
ABEX PUMP
TEE-IN TRANSDUCER
PSI
0 IT
500
0
SEC .008
TIME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ABEX PUMP
CLAMP-ON TRANSDUCER
PSI
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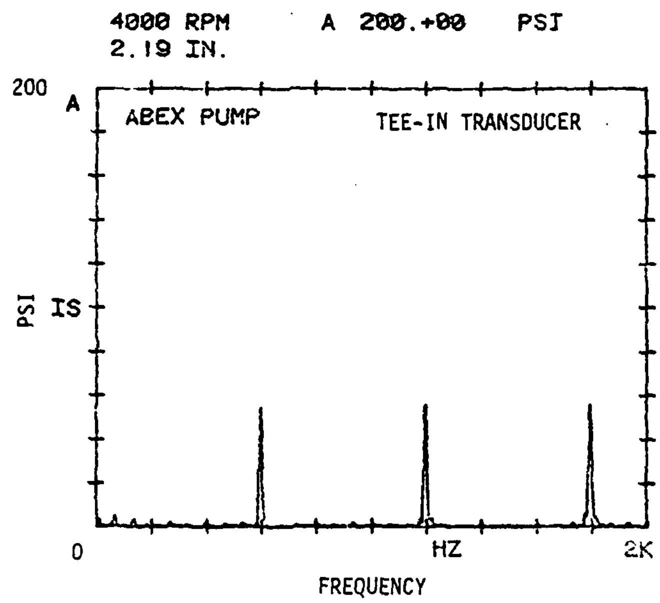
TIME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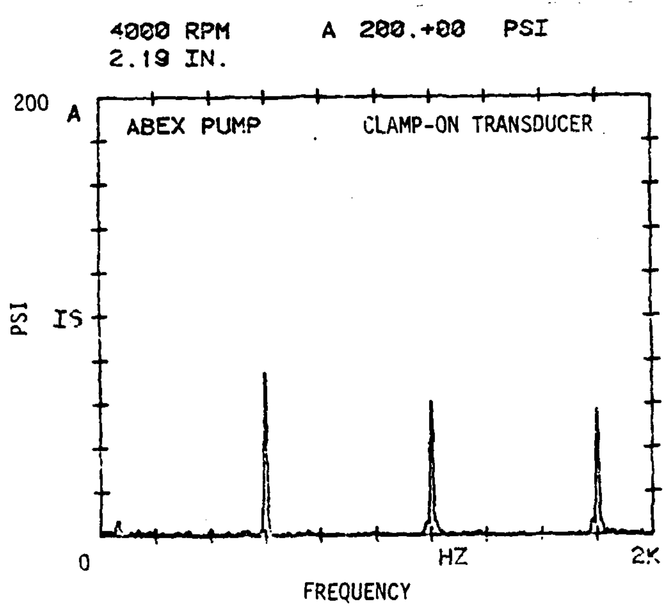
2K
FREQUENCY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200
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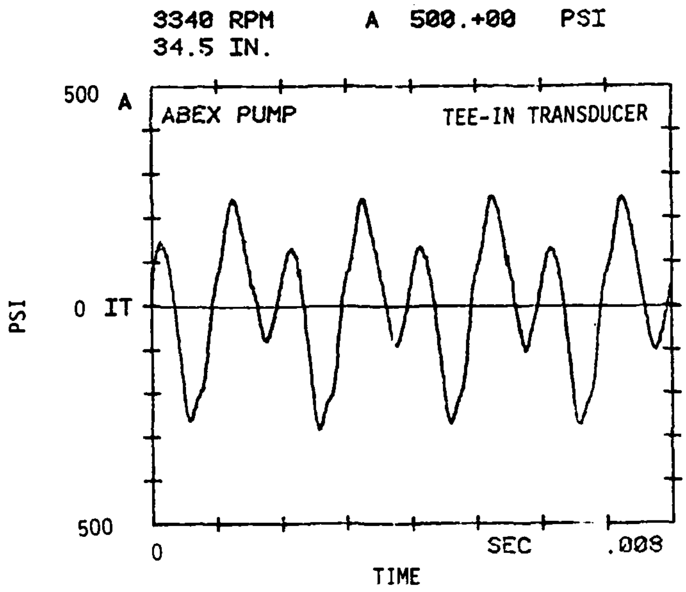
ABEX PUMP
CLAMP-ON TRANSDUCER
PSI
IS
0
HZ
2K
FREQUENCY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A 500.+00 PSI
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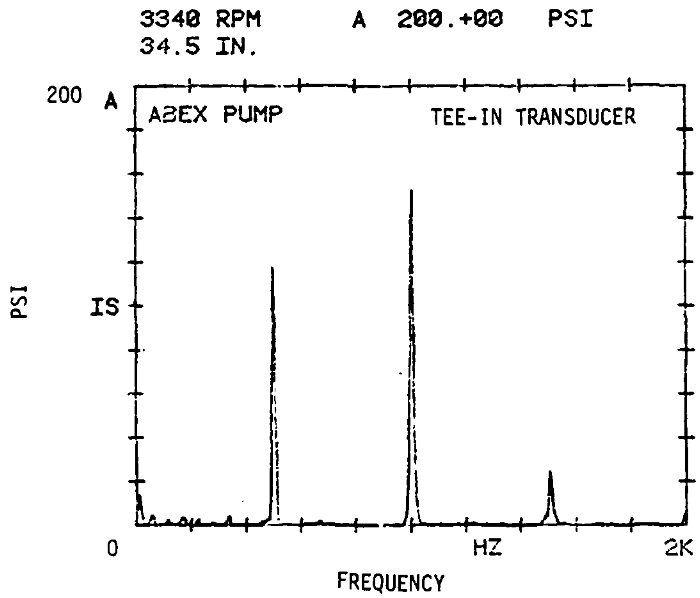
A
ABEX PUMP
TEE-IN TRANSDUCER
PSI
0 IT
500
0
SEC
.008
TIME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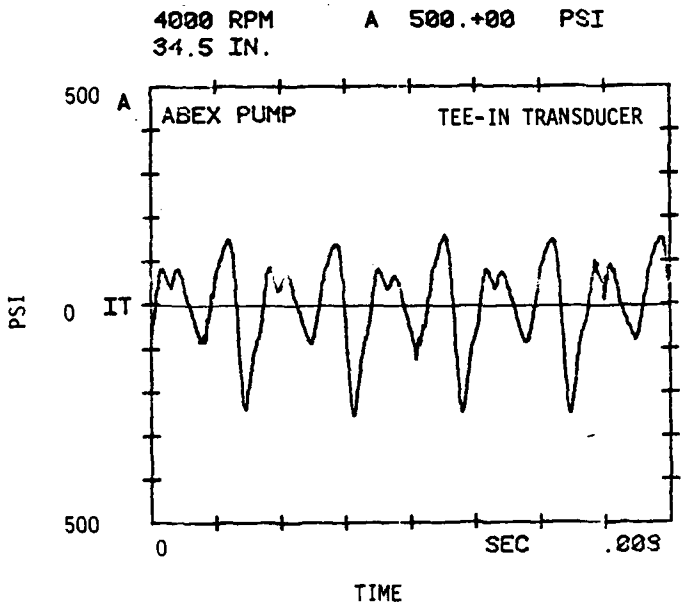
A 200.+00 PSI
34.5 IN.
200
A
ABEX PUMP
TEE-IN TRANSDUCER
PSI
IS
0
HZ
2K
FREQUENCY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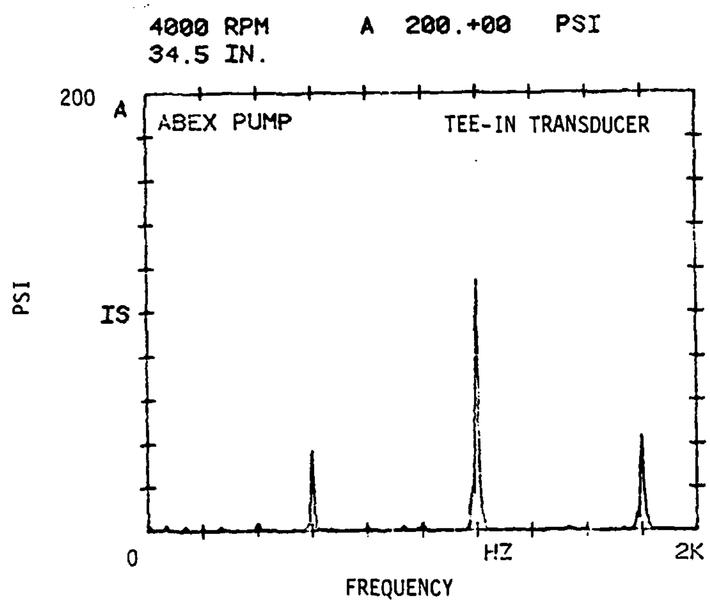
34.5 IN.
500 A
ABEX PUMP
TEE-IN TRANSDUCER
PSI
0 IT
500
0
SEC
.008
TIME


4000 RPM A 200.+00 PSI
34.5 IN.
200 A
ABEX PUMP
TEE-IN TRANSDUCER
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2K
FREQUENCY

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APPENDIX C

ACTUATOR PISTON AND ROD SEALS

ACTUATOR	TYPE	SYSTEM	LOCATION	STAGE	RING	PART NUMBER	SUPPLIER
L/H UHT	Piston	FC-1	---	---	D-D	S30660-327-14	Shamban
					B-U	S33157-327-14	Shamban
					O-R	MS28775-327	---
		FC-2	---	---	T-S	7329MT-160-4750	Greene, Tweed
	Rod	FC-1&2	C/D	1st	D-D	S30650-217-14	Shamban
					B-U	S33157-217-14	Shamban
					O-R	M83461/1-217	
				2nd	B-U	MS27595-217	
					O-R	M83461/1-217	
		FC-2	O/S	1st	D-D	S30650-326-17	Shamban
					B-U	S33157-326-14	Shamban
					O-R	M83461/1-326	
				2nd	B-U	MS27595-326	
					O-R	M83461/1-326	
R/H UHT	Piston	FC-1	---	---	+S	S30772-327-19	Shamban
					B-U	S33157-327-19	Shamban
		FC-2	---	---	+S	S30772-329-19	Shamban
					B-U	S33157-329-19	Shamban
	Rod	FC-1	C/D	1st	D-D	S30650-217-14	
					B-U	S33157-217-14	
					O-R	M83461/1-217	
				2nd	B-U	MS27595-217	
					O-R	M83461/1-217	
		FC-2	C/D	1st	E-C	591-21700-160-0190	Greene, Tweed
				2nd	B-U	MS27595-217	
			O/S	1st	+S	S30775-326P-19	Shamban
					B-U	S33157-326-19	Shamban
				2nd	B-U	MS27595-326	
					O-R	M83461/1-326	
Rudder	Piston	FC-1	---	---	D-D	S30660-214-14	Shamban
					B-U	S33157-214-14	Shamban
					O-R	S30397-214P	Shamban
		FC-2	---	---	T-S	7214MT-972-47801	Greene, Tweed
	Rod	FC-1&2	O/S&C/D	1st	D-D	S30650-211-14	Shamban
					B-U	S33157-211-14	Shamban
					O-R	M83461/1-211	
				2nd	B-U	CEC4862-211NC	Conover
					O-R	M83461/1-211	
Yaw AFCS	Piston	FC-1	---	---	T-S	7210MT-160-4750	Greene, Tweed
	Rod	FC-1	O/S	---	D-D	S30650-116-14	Shamban
					B-U	S33012-116-14	Shamban
					O-R	M83461/1-116	
RFI	Piston	FC-1&2	---	---	T-S	7116MT-160-4750	Greene, Tweed
	Rod	FC-1&2	O/S&C/D	1st	D-D	S30650-116-114	
					B-U	S33157-116-114	
					O-R	M83461/1-116	
				2nd	B-U	CEC5057-116NC	Conover
					O-R	M83461/1-116	

ACTUATOR	TYPE	SYSTEM	LOCATION	STAGE	RING	PART NUMBER	SUPPLIER
L/H Spoiler/ Deflector	Piston	FC-1	---	---	T-S	7116MT-160-4750	Greene, Tweed
		FC-2			T-S	7210MT-160-4750	Greene, Tweed
	Rod	FC-1&2	C/D	1st	D-D	S30650-113-14	Shamban
					B-U	S33157-113-14	Shamban
					O-R	M83461/-113	
				2nd	B-U	CEC4862-113	Conover
					O-R	M83461/-113	
		FC-2	O/S	1st	D-D	S30650-210-14	Shamban
					B-U	S33157-210-14	Shamban
					O-R	M83461/1-210	
				2nd	B-U	CEC4862-210NC	Conover
					O-R	M83461/1-210	
L/H Aileron	Piston	FC-2	---	---	T-S	721DOMT-160-4750	Greene, Tweed
	Rod	FC-2	C/D	1st	D-D	S30650-113-14	Shamban
					B-U	S33157-113-14	Shamban
					O-R	M83461/1-113	
				2nd	B-U	MS27595-113	
					O-R	M83461/1-113	
			O/S	1st	D-D	S30650-210-14	Shamban
					B-U	S33157-210-14	Shamban
					O-R	M83461/1-210	
				2nd	B-U	MS27595-210	
					O-R	M83461/1-210	
L.E. Flap	Piston	FC-2	---	---	T-S	7217MT-972-9009	Greene, Tweed
	Rod	FC-2	---	---	B-U	CEC5056-211	Conover
					O-R	M83461/1-211	
Speed Brake	Piston	FC-1	---	---	T-S	7331MT-972-9009	Greene, Tweed
	Rod	FC-1	---	---	B-U	CEC5056-331	Conover
					O-R	M83461/1-331	
Seal Test Fixture	Piston	FC-1	---	---	+S	S30772-3044	Shamban
					B-U	S33157-330-19	Shamban
	Rod	FC-1	inbd	1st	+S	S30775-218P-19	Shamban
					B-U	S33157-218-19	Shamban
				2nd	Same as 1st stage except 2 B-U's on outside		
			outbd	1st	Same as inbd. 1st stage		
				2nd	H-S	S33353-218P-19	
	Piston	FC-2	---	---	CGT	266-33000-964-1200	Greene, Tweed
	Rod	FC-2	inbd & outbd	1st	CGTL	265-21800-964-1200	Greene, Tweed
				2nd	TRAP	4635-21800H-964	Greene, Tweed

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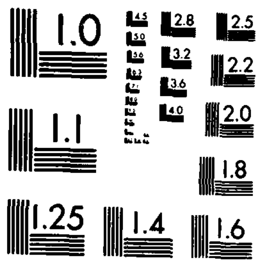
APPENDIX D

PHOTOGRAPHS AND DRAWINGS OF LHS ACTUATORS

Contents

* See Appendix 'C' for piston seal part numbers

AD-A169 884 FABRICATION AND TESTING OF LIGHTWEIGHT HYDRAULIC SYSTEM 3/4
SIMULATOR HARDWAR..(U) ROCKWELL INTERNATIONAL COLUMBUS
OH NORTH AMERICAN AIRCRAFT OP.. W N BICKEL ET AL.
UNCLASSIFIED JAN 86 NA-85-0134 NADC-79024-60 F/G 13/7 NL


1.0
1.1
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1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

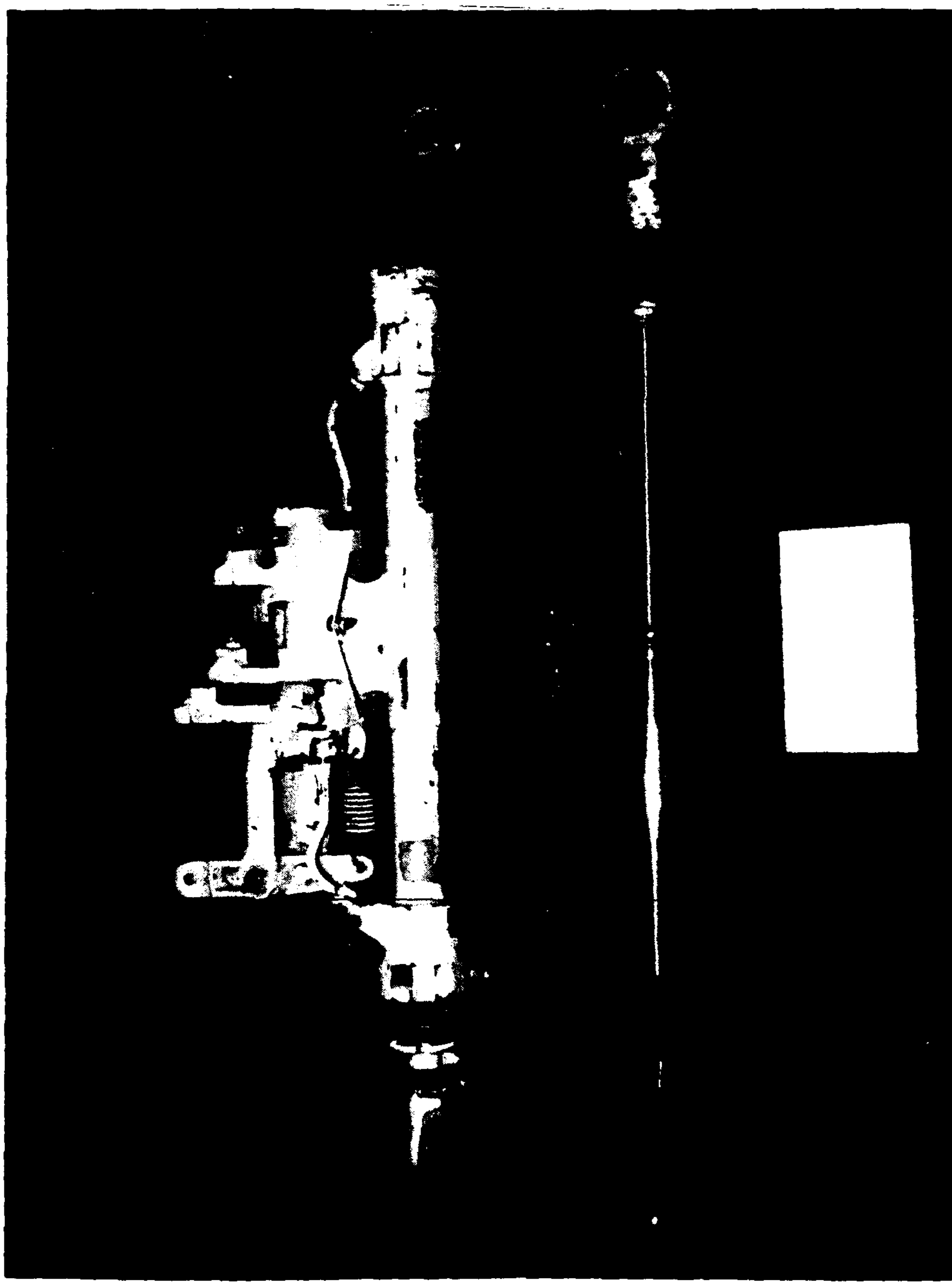

FIGURE D-1. Aileron actuator

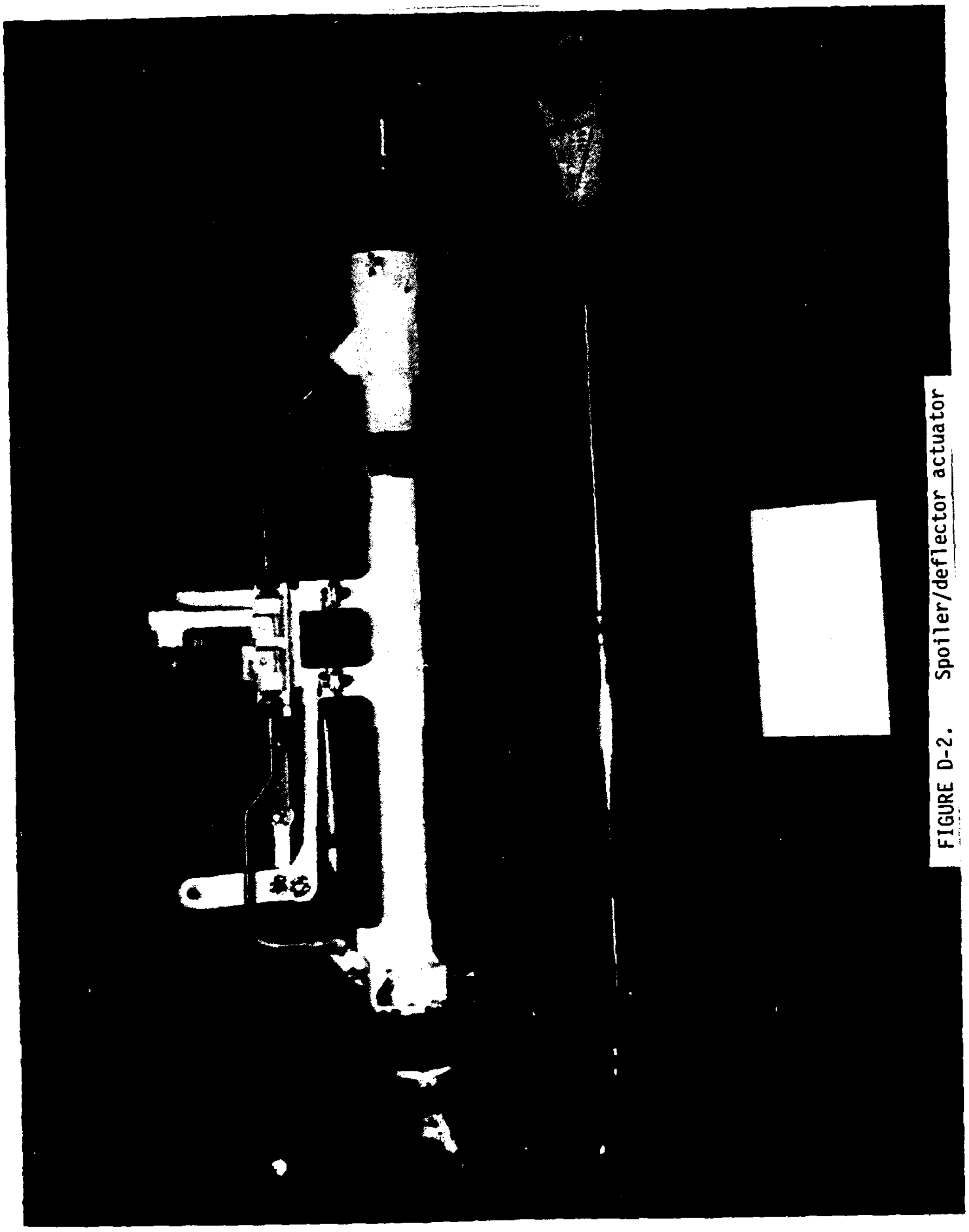

FIGURE D-2. Spoiler/deflector actuator

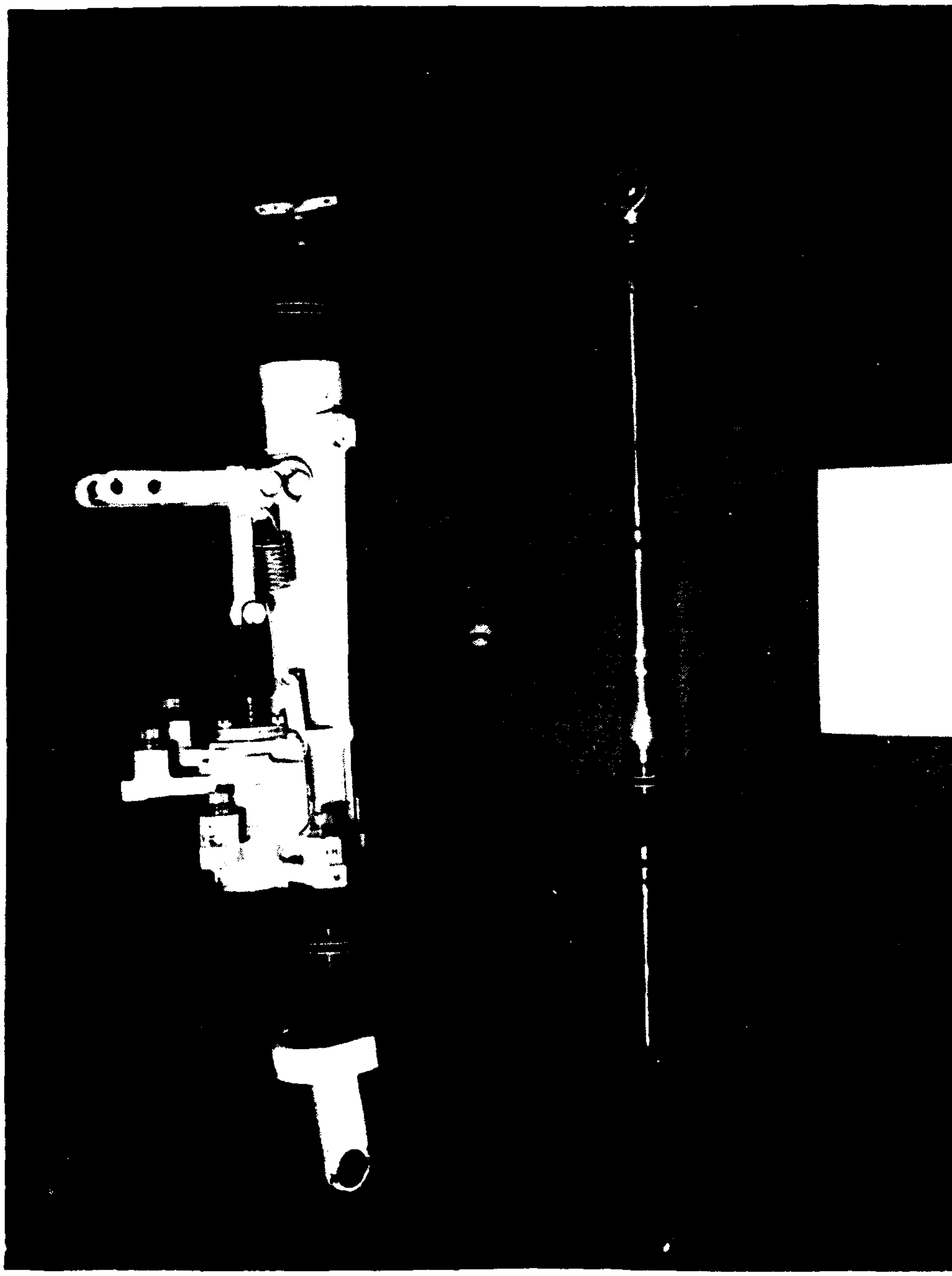

FIGURE D-3. RFI actuator

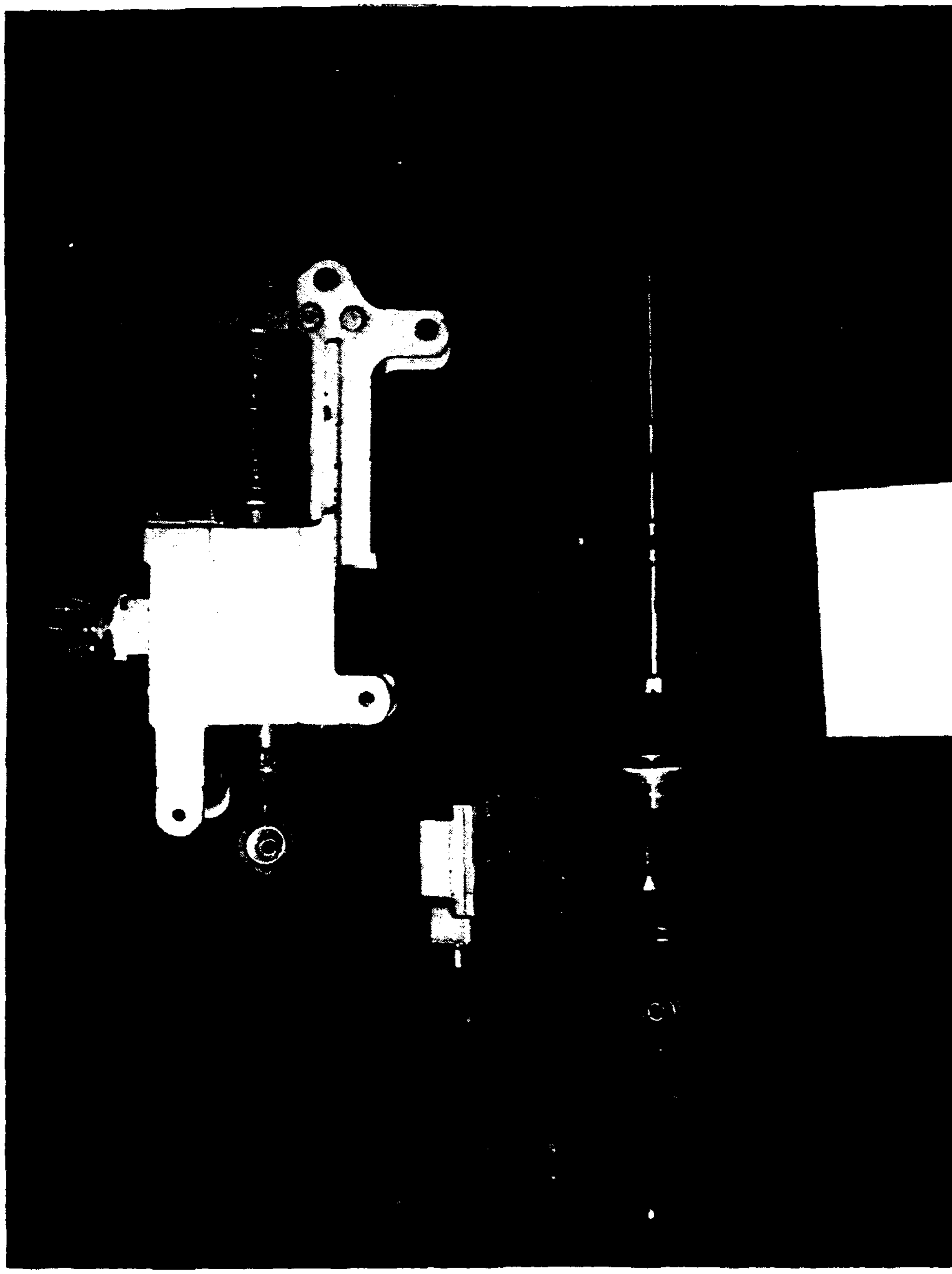

FIGURE D-4. AFCS yaw actuator

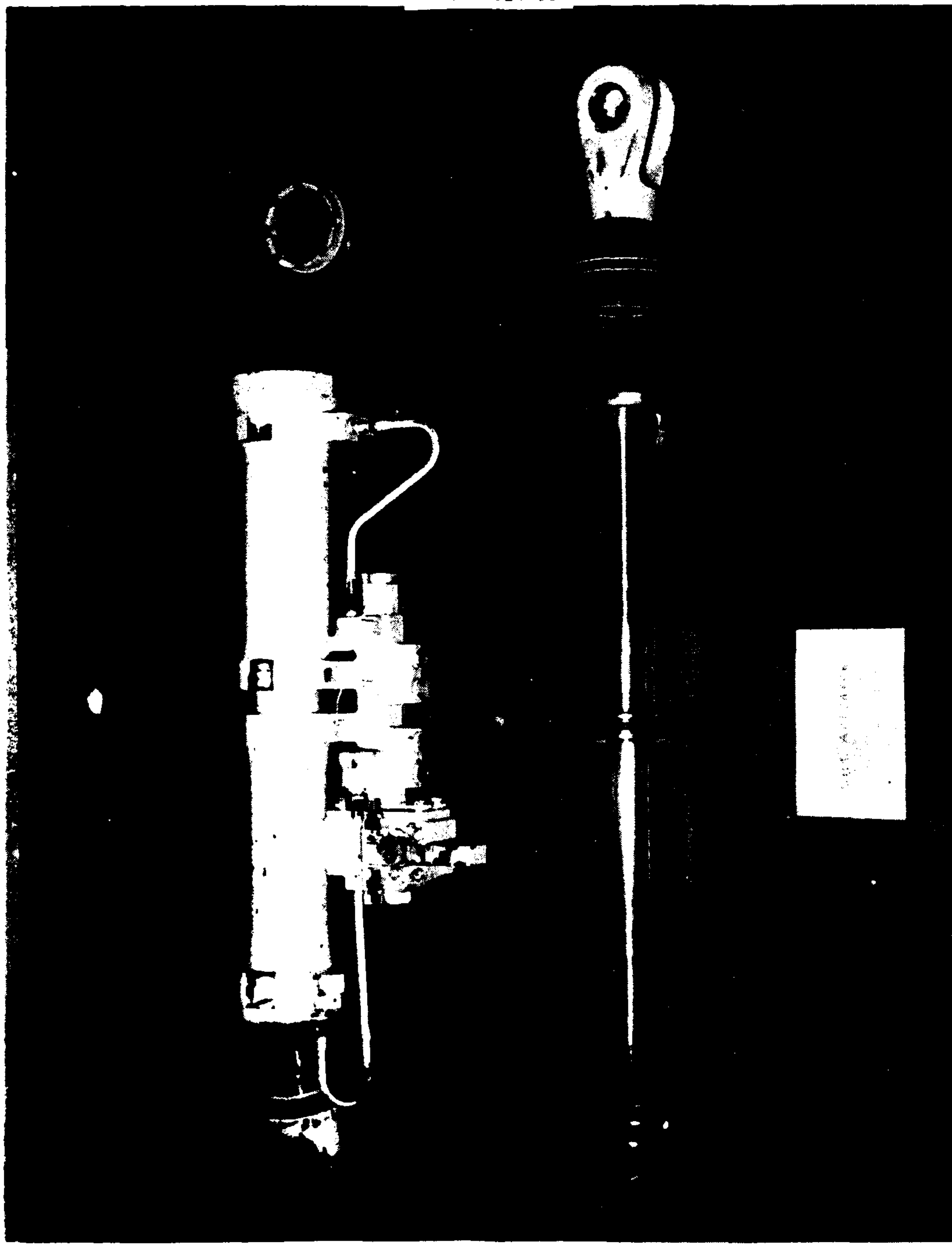

FIGURE D-5. UHT actuator

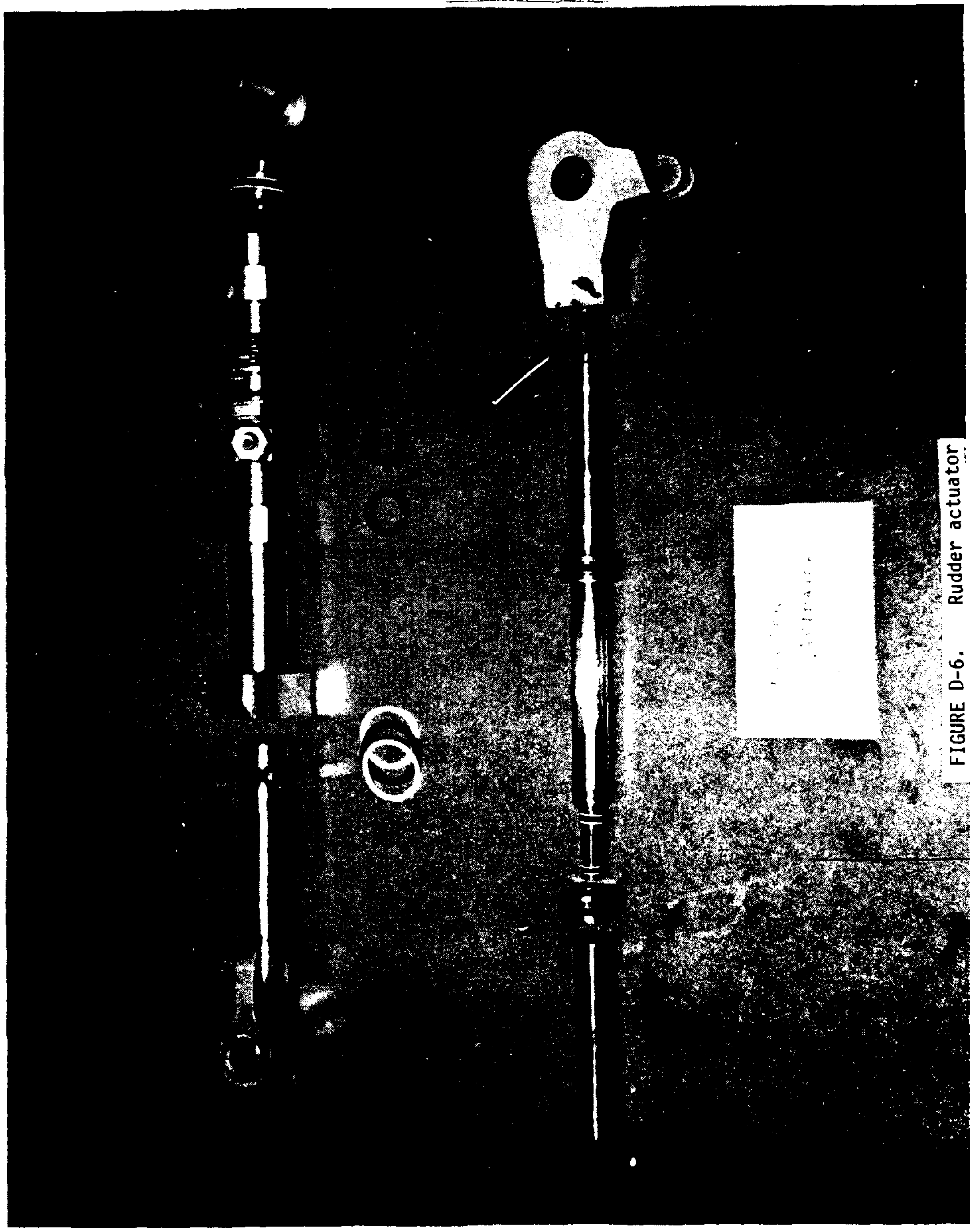

FIGURE D-6. Rudder actuator

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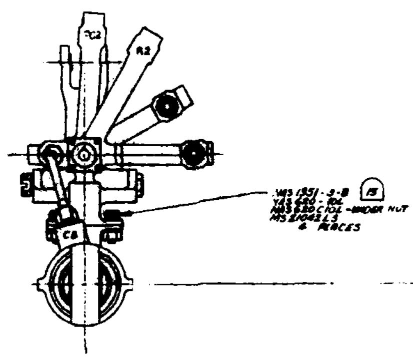
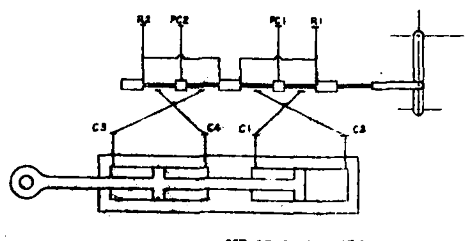
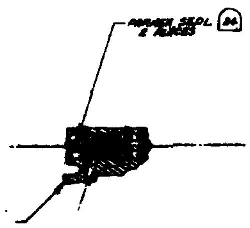
83-00511

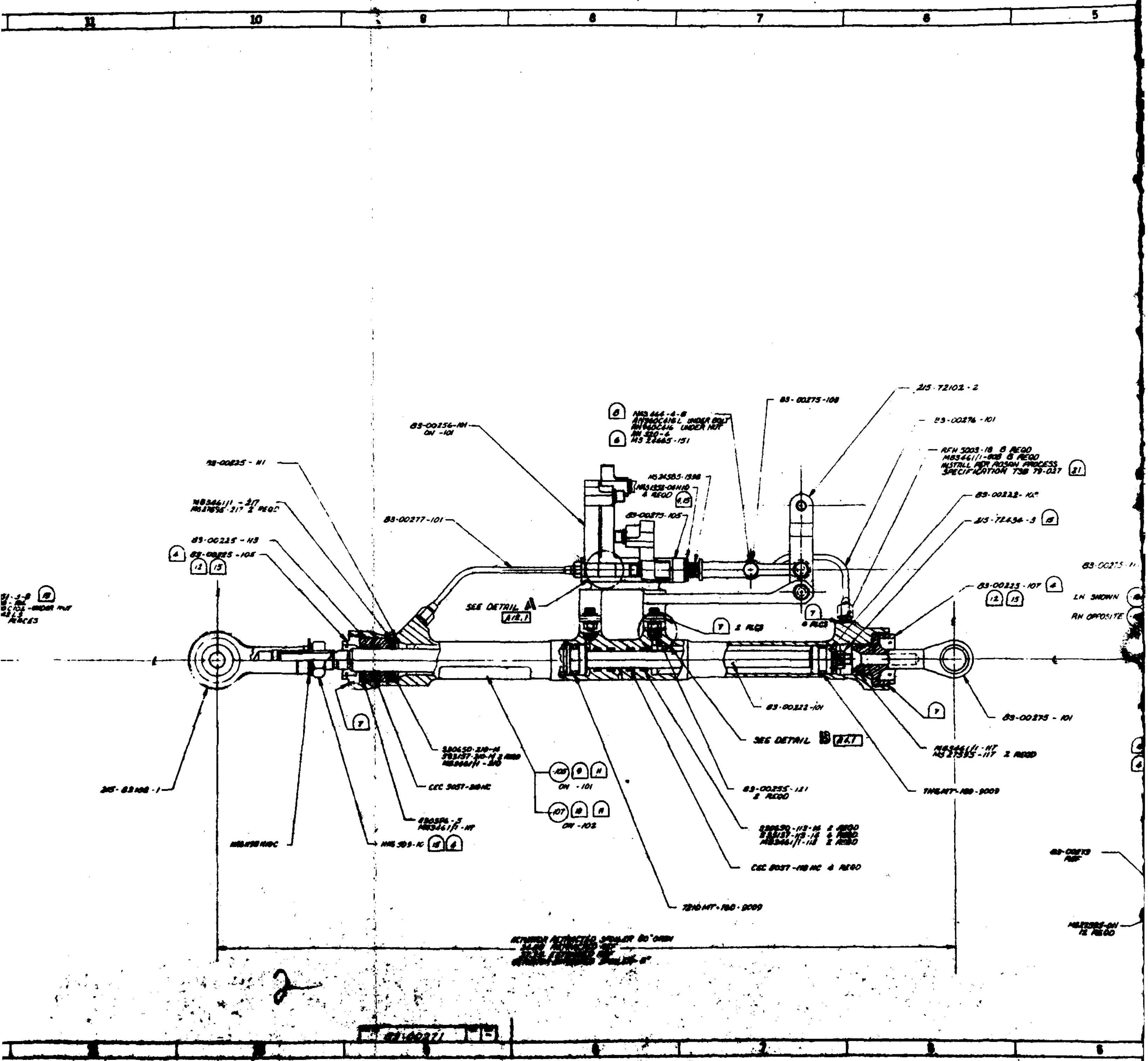




ACTUATOR SCHEMATIC



DETAIL A



11
10
9
8
7
6
5
83-00256-101
ON -101
MS 24665-151
83-00277-101
83-00225 - 113
83-00225 - 105
SEE DETAIL A
83-00275-105
83-00275-108
215 · 72102 · 2
83-00276 - 101
RFH 5003-18 8 REQD
INSTALL PER ROSAN PROCESS
SPECIFICATION T38 79-037
215-72434-3
83-00225 - 107
LH SHOWN
RH OPPOSITE
83-00222-101
83-00275 - 101
SEE DETAIL B
CEC 3057-118 HC
ON -101
ON -102
83-00255-121
2 REQD
CEC 3057-118 HC 4 REQD

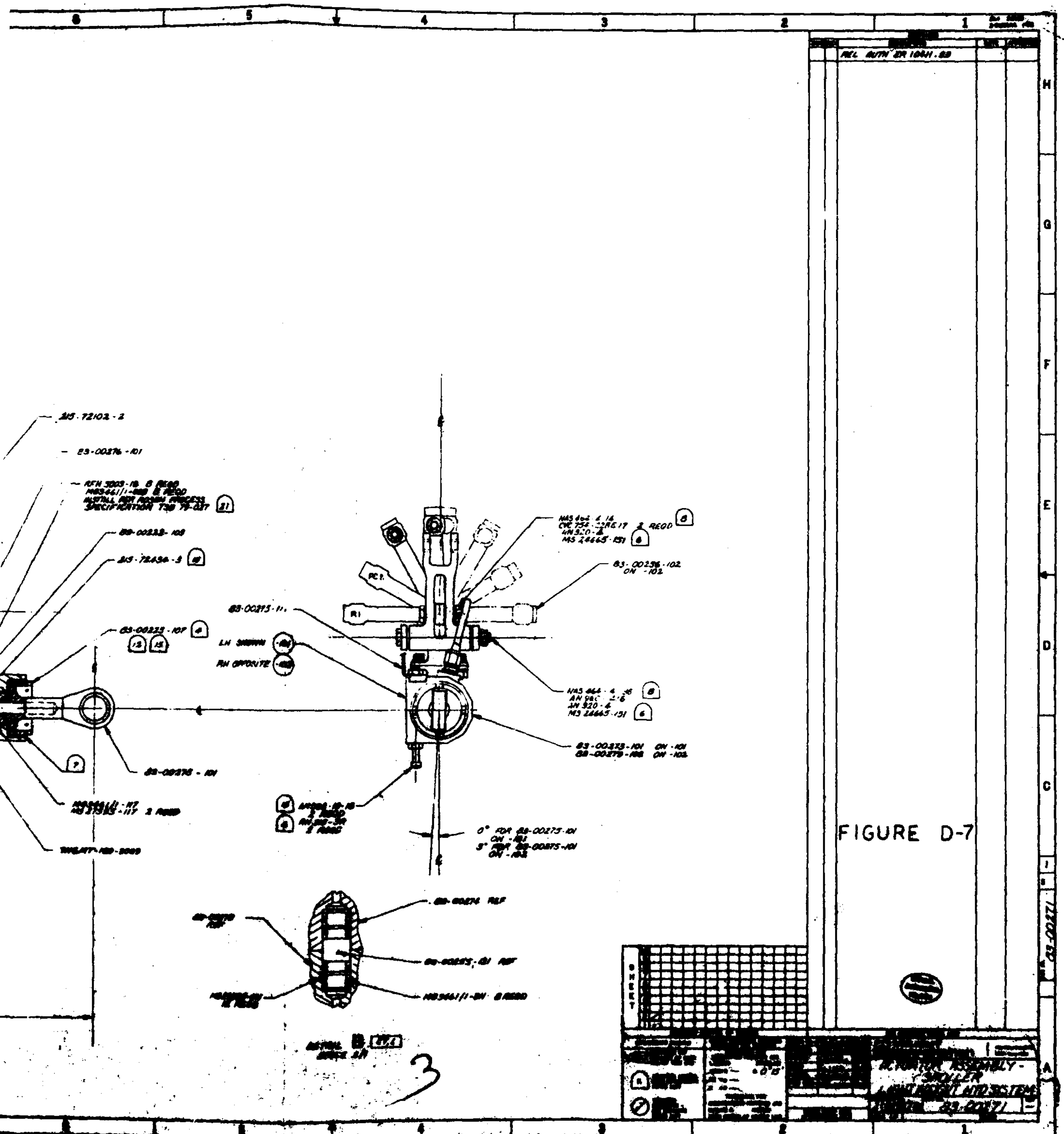
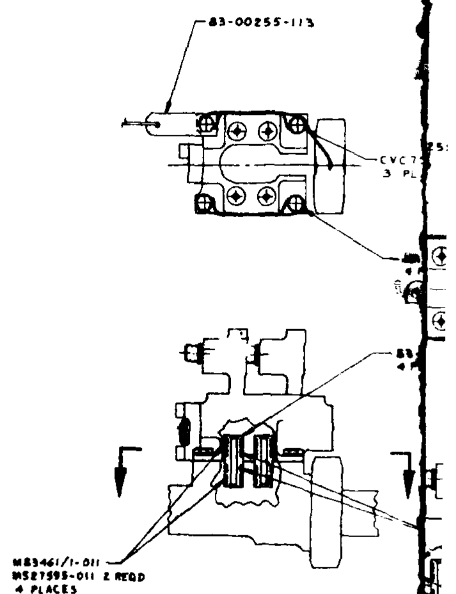
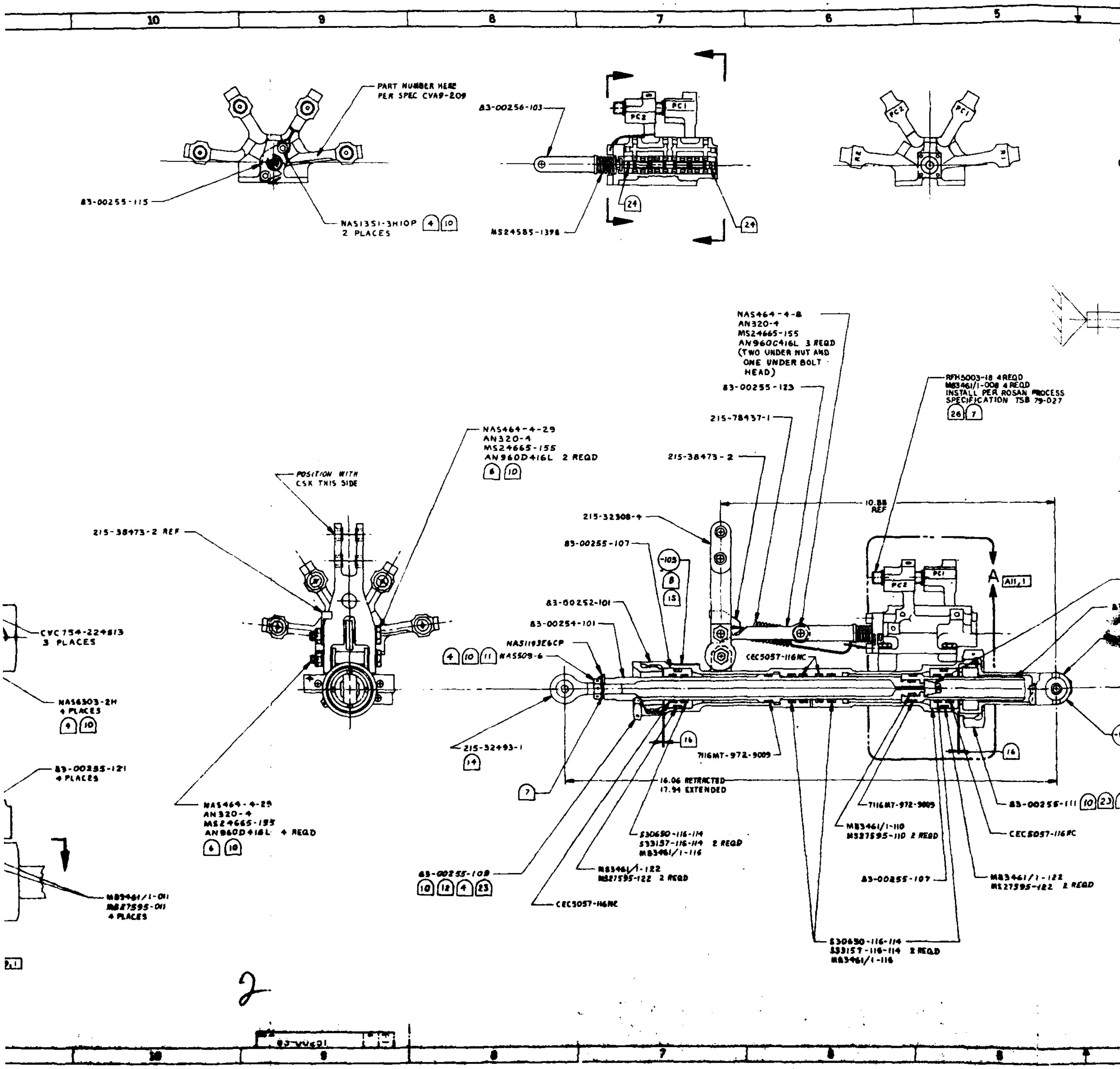


FIGURE D-7



DETAIL A D5.1



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NAS1351-3H10P 4 10 2 PLACES
83-00256-103
MS24585-1398
PC1
PC2
24
NAS464-4-8
AN320-4
MS24665-155
AN960C416L 3 REQD (TWO UNDER NUT AND ONE UNDER BOLT HEAD)
83-00255-123
215-78437-1
215-38473-2
RFH5003-18 4 REQD
MB3461/1-008 4 REQD
INSTALL PER ROSAN PROCESS SPECIFICATION TSB 79-027
26 7
NAS464-4-29
AN320-4
MS24665-155
AN960D416L 2 REQD
6 10
POSITION WITH CSK THIS SIDE
215-38473-2 REF
10.88 REF
215-32308-4
83-00255-107
-105
8
15
A
A11, 1
83-00252-101
83-00254-101
NAS1193E6CP
4 10 11 NAS509-6
CEC5057-116NC
CVC754-224813 3 PLACES
NAS6303-2H 4 PLACES
4 10
215-32493-1
14
7
16
7116MT-972-9009
16.06 RETRACTED
17.94 EXTENDED
83-00255-121 4 PLACES
NAS464-4-29
AN320-4
MS24665-155
AN960D416L 4 REQD
6 10
83-00255-111 10 23
CEC5057-116NC
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MB3461/1-110
MS27595-110 2 REQD
S30650-116-114
S33157-116-114 2 REQD
MB3461/1-116
MB3461/1-122
MS27595-122 2 REQD
83-00255-107
MB3461/1-122
MS27595-122 2 REQD
83-00255-109
10 12 4 23
CEC5057-116NC
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S33157-116-114 2 REQD
MB3461/1-116
2

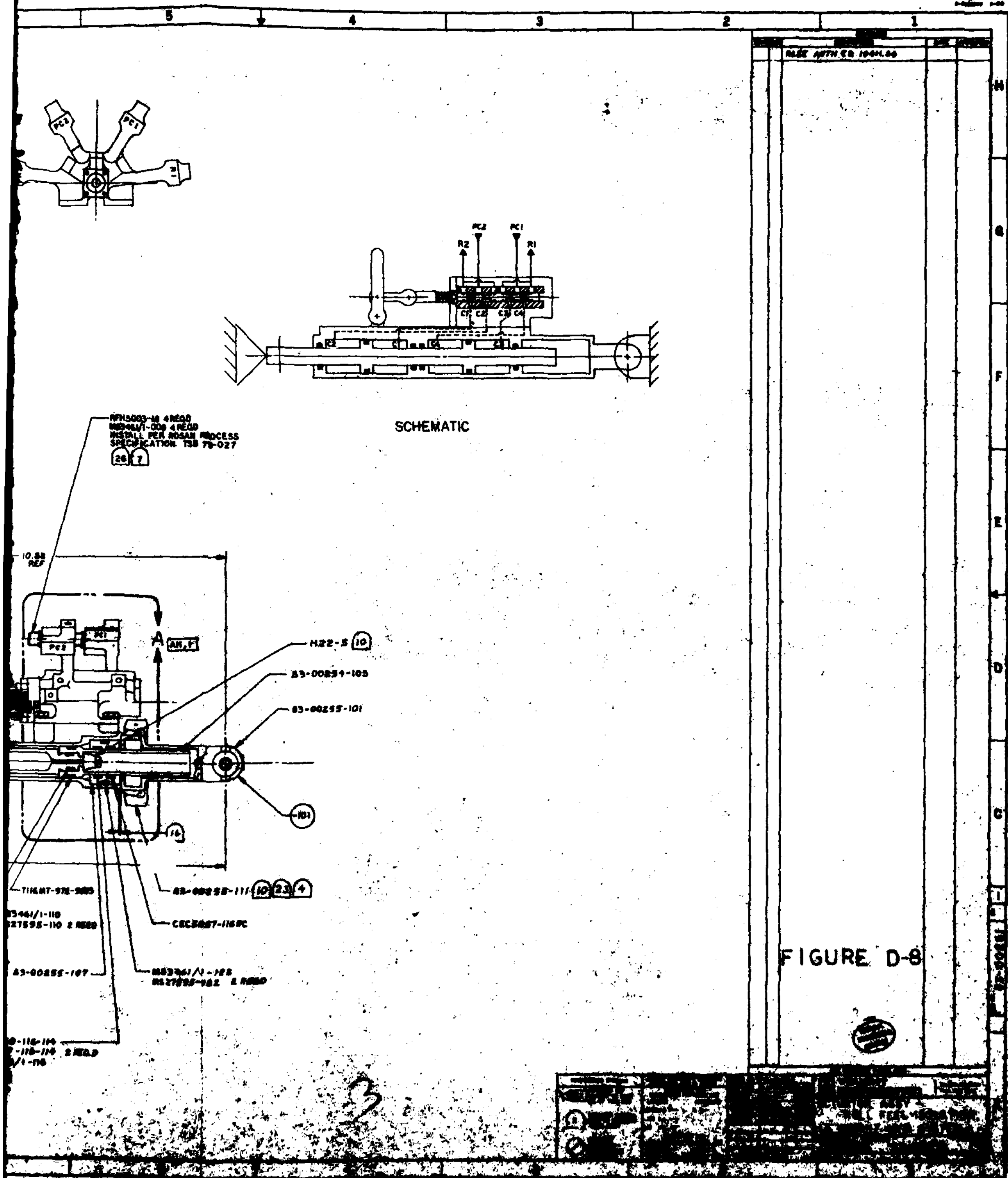
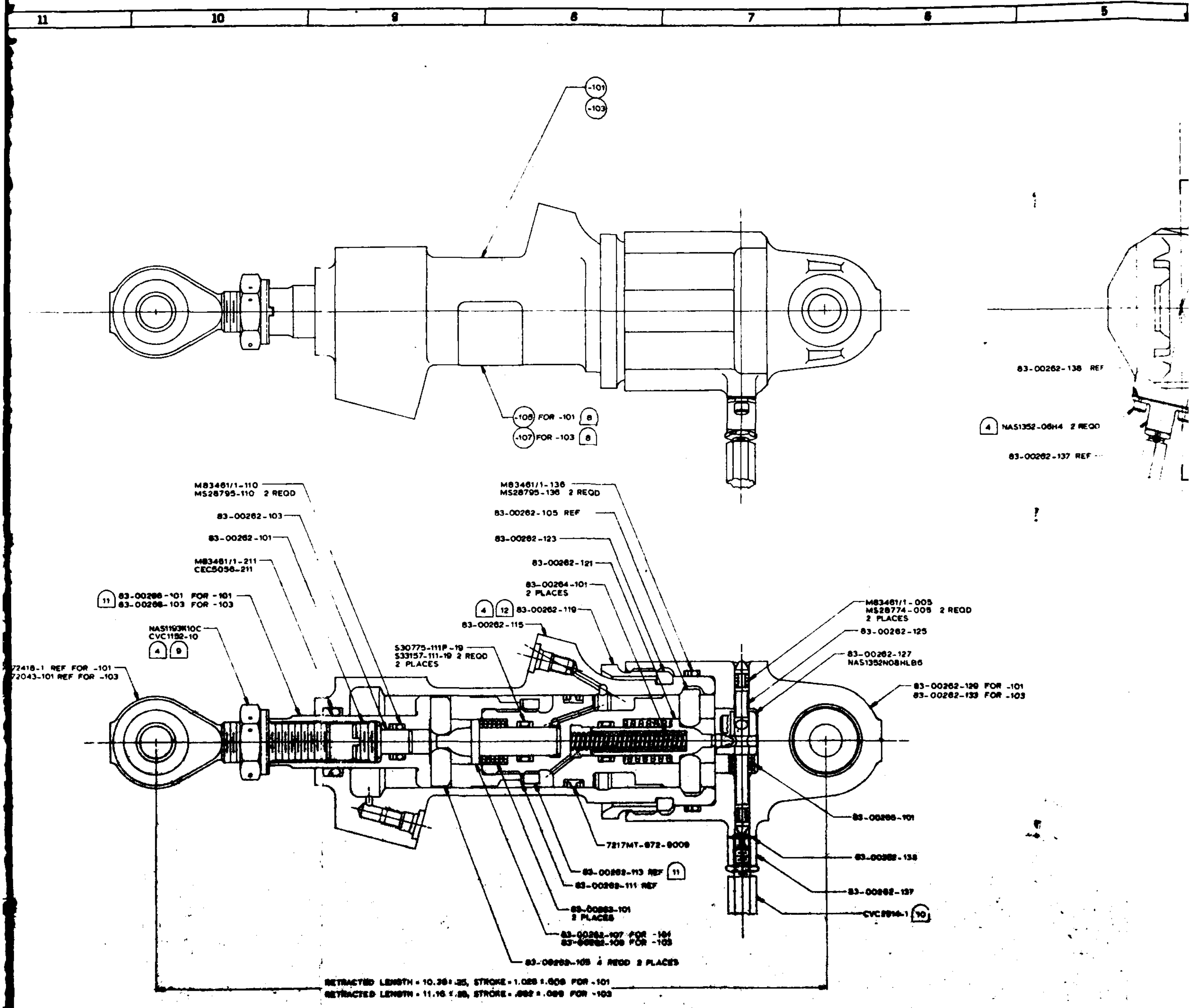

PC2
PC1
R2
R1
C1
C2
C3
C4
SCHEMATIC
INSTALL PER ROSAN PROCESS
SPECIFICATION TSB 79-027
10.88
REF
H22-5
83-00254-105
83-00255-101
83-00255-107
CEC5087-116PC

FIGURE D-8

215-72418-1 REF FOR -1
218-72043-101 REF FOR -



SECT. A-A

ALL PORTS ROTATED TO PLANE A-A

2

83-00261

11 | 10 | 9 | 8 | 7 | 6 | 5

RELEASE AUTH ER 10411.32

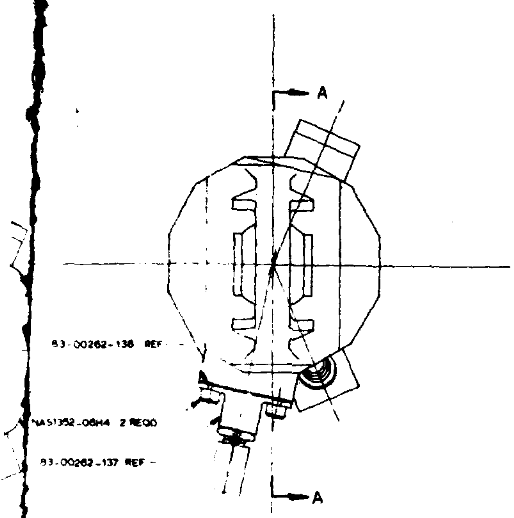


FIGURE D-9

83-00261

3

CYLINDER ASSY, ACTUATING, WING LEADING EDGE FLAPS LHS

83-00261

APPENDIX E

WEIGHT AND SPACE ANALYSIS UPDATE

Contents

Table E-1. Component Weight Summary

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM**
1	2	PUMP	14.90	18.5
2/3	1 EA	RESERVOIR	25.28	24.40
4	2	RELIEF VALVE, HIGH PRESS	.81	.46
5	2	RELIEF VALVE, LOW PRESS	1.63	.43
6	2	FILTER, PRESSURE	2.75	1.81 (H.O.)
7	2	FILTER, RETURN	2.75	1.40
8	1	FILTER, CASE DR	1.48	1.48
9	1	FILTER, EMER PWR PKG	N/A	N/A
10	2	PRESSURE SNUBBER	.09	.07
11	2	PRESSURE TRANSMITTER/SWITCH	1.45	1.50
12	2	BLEED VALVE	.05	.05
13	1	ACCUMULATOR	3.11	1.75
14	1	PRESSURE GAGE	.18	.11
15	1	SOLENOID VALVE-ACCUM.ISOL.	1.25	(1.40)(H.O.)
16	2	PRESS.DISC-EXTERNAL ACCESS	.67	.23
17	2	SUCTION DISC-EXTERNAL ACCESS	.98	.23
18	2	PRESS. DISC-PUMP	1.00	.23
19	2	SUCTION DISC-PUMP	1.00	.24
20	2	CASE DRAIN DISC-PUMP	.42	.42
21	1	SELECTOR VALVE-SPEED BR	3.30	3.25 (H.O.)
22	-	DELETED	-	-
23	1	EMER. POWER PACKAGE	N/A	N/A
24	1	FLOW SENSITIVE PRESS.REG.	N/A	N/A
25	3	SELECTOR VALVE-AFCS SHUTOFF	.56	1.56
26	-	DELETED	-	-
27	1	CHARGING VALVE-ACCUM.	.11	.11
28	1	RESTRICTOR-SPEED BRAKE	.40	.03
29	1	RESTRICTOR-L.E. FLAP	.15	.09
30	4	RESTRICTOR-L.E. FLAP O.B. PANEL	.13	.09
31	2	RESTRICTOR-L.E. FLAP INBD. PANEL	.17	.09
32	2	RESTRICTOR-L.E. FLAP INBD. PANEL	.17	.28
33	1	SWIVEL-SPEED BRAKE EXTEND	.69	.81
34	1	SWIVEL-SPEED BRAKE RETRACT	.75	.81
35	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
36	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
37	2	SWIVEL-WING FOLD	1.85	1.75
38/	-	DELETED	-	-

Table E-1. Component Weight Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM**
43	1	VALVE-SHUT OFF	--	2.31
44	4	CHECK VALVE-RUD.,SP.BR., RET.,FLAP	.07	.08
45	1	CHECK VALVE-SP.BRAKE	.07	.08
46	2	CHECK VALVE-UHT PRESS & RET.	.11	.09
47	1	CHECK VALVE-SP.BRAKE	.10	.10
48	4	CHECK VALVE-RUN AROUND CIRCUITS	.18	.13
49	3	CHECK VALVE-FILTER RUN AROUND	.18	.22
50	1	CHECK VALVE-SP.BRAKE	.35	.23
51	3	CHECK VALVE-RETURN FILTER	.35	.26
52	2	CHECK VALVE-PUMP PRESS	.36	.28
53	2	CHECK VALVE-SYSTEM FILL	.07	.16
54	2	CHECK VALVE-UHT PRESS	.11	.09
55	1	CHECK VALVE-CASE DRAIN	.07	.144
56	1	CHECK VALVE RAT BY-PASS		.26
57/63	-	DELETED	-	-
64	1	MANIFOLD, PRESSURE	.58	1.00
65	1	MANIFOLD, RETURN	.55	.64
66	1	MANIFOLD, RELIEF VALVE	.79	.69 (H.O.)
67	1	HOSE ASSY-PUMP PRESSURE, FC1	3.14	2.18
68	1	HOSE ASSY-PUMP PRESSURE, FC2	3.14	2.18
69	1	HOSE ASSY-PUMP SUCTION, FC1	2.15	.28
70	1	HOSE ASSY-PUMP SUCTION, FC2	2.15	.18
71	1	HOSE ASSY-CASE DRAIN,FC1	.63	.63
72	1	HOSE ASSY-CASE DRAIN,FC2	.75	.75
73	1	CHECK VALVE-RAT SUCTION	N/A	N/A
74	1	MANIFOLD-ACCUMULATOR	.31	.31
75	1	CHECK VALVE-CASE DRAIN	.07	.144
76	1	MANIFOLD-SUCTION DISCONNECT		
77	1	HOSE ASSY-AILERON PRESSURE	.3	.336
78	1	HOSE ASSY-AILERON RETURN	.3	.331
79	1	HOSE ASSY-AILERON RETURN	.41	.589
80	1	HOSE ASSY-AILERON PRESSURE	.42	.509
81	1	HOSE ASSY-AILERON PRESSURE	.3	.331

Table E-1. Component Weight Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB EQUIV. 3000 PSI SYSTEM	LHS SYSTEM**
82	1	HOSE ASSY-AILERON RETURN	.3	.335
83	1	HOSE ASSY-AILERON RETURN	.42	.578
84	1	HOSE ASSY-AILERON PRESSURE	.39	.522
85	1	SELECTOR VALVE-L.E. FLAP	1.16	3.0 (H.O.)
101	2	AILERON ACTUATOR	16.35	15.41 (H.O.)
102	2	SPOILER ACTUATOR	16.35	10.75 (H.O.)
103	1	RUDDER ACTUATOR	8.55	6.40 (H.O.)
104	2	UHT ACTUATOR	33.80	25.35 (H.O.)
105	1	ROLL FEEL ACTUATOR	11.64	9.12 (H.O.)
106	3	AFCS ACTUATOR	15.79	14.95 (H.O.)
107	1	SPEED BRAKE ACTUATOR	46.41	43.93 (H.O.)
108	8	LEADING EDGE FLAP ACTUATOR	6.73	5.30 (H.O.)
109	1	RUDDER SERVO VALVE	3.09	2.86

*See Figure 3

**H.O. = Hog-Out

N/A = Not Applicable

Table E-2. Component Volume Summary

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3 EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
1	2	PUMP	171	118
2/3	1 EA	RESERVOIR	817	593
4	2	RELIEF VALVE, HIGH PRESS	7	4
5	2	RELIEF VALVE, LOW PRESS	17	7
6	2	FILTER, PRESSURE	62	24
7	2	FILTER, RETURN	62	31
8	1	FILTER, CASE DR	28	28
9	1	FILTER, EMER PWR PKG	N/A	N/A
10	2	PRESSURE SNUBBER	<1	<1
11	2	PRESSURE TRANSMITTER/SWITCH	22	22
12	2	BLEED VALVE	1	1
13	1	ACCUMULATOR	40	25
14	1	PRESSURE GAGE	1	1
15	1	SOLENOID VALVE-ACCUM.ISOL.	15	9
16	2	PRESS.DISC-EXTERNAL ACCESS	9	3
17	2	SUCTION DISC-EXTERNAL ACCESS	12	7
18	2	PRESS. DISC-PUMP	21	6
19	2	SUCTION DISC-PUMP	21	9
20	2	CASE DRAIN DISC-PUMP	5	5
21	1	SELECTOR VALVE-SPEED BR	50	35
22	-	DELETED	-	-
23	1	EMER. POWER PACKAGE	N/A	N/A
24	1	FLOW SENSITIVE PRESS.REG.	N/A	N/A
25	3	SELECTOR VALVE-SAS SHUTOFF	10	13
26	-	DELETED	-	-
27	1	CHARGING VALVE-ACCUM.	<1	<1
28	1	RESTRICTOR-SPEED BRAKE	1	<1
29	1	RESTRICTOR-L.E. FLAP	2	<1
30	4	RESTRICTOR-L.E. FLAP O.B. PANEL	2	<1
31	2	RESTRICTOR-L.E. FLAP INBD. PANEL	2	<1
32	2	RESTRICTOR-L.E. FLAP INBD. PANEL	2	<1
33	1	SWIVEL-SPEED BRAKE EXTEND	8	10
34	1	SWIVEL-SPEED BRAKE RETRACT	10	12
35	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
36	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
37	2	SWIVEL-WING FOLD	17	16
38/43	-	DELETED	-	-

Table E-2. Component Volume Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
44	4	CHECK VALVE-RUD.,SP.BR., RET.,FLAP	< 1	< 1
45	1	CHECK VALVE-SP.BRAKE	< 1	< 1
46	2	CHECK VALVE-UHT PRESS & RET.	1	< 1
47	1	CHECK VALVE-SP.BRAKE	< 1	< 1
48	4	CHECK VALVE-RUN AROUND CIRCUITS	1	< 1
49	3	CHECK VALVE-FILTER RUN AROUND	1	< 1
50	1	CHECK VALVE-SP.BRAKE	1	< 1
51	3	CHECK VALVE-RETURN FILTER	1	< 1
52	2	CHECK VALVE-PUMP PRESS	1	< 1
53	2	CHECK VALVE-SYSTEM FILL	< 1	< 1
54	2	CHECK VALVE-UHT PRESS	1	< 1
55	1	CHECK VALVE-CASE DRAIN	< 1	< 1
56	1	CHECK VALVE RAT BY-PASS	N/A	N/A
57/63	-	DELETED	-	-
64	1	MANIFOLD, PRESSURE	7	2
65	1	MANIFOLD, RETURN	6	3
66	1	MANIFOLD, RELIEF VALVE	8	5
67	1	HOSE ASSY-PUMP PRESSURE, FC1	30	19
68	1	HOSE ASSY-PUMP PRESSURE, FC2	37	24
69	1	HOSE ASSY-PUMP SUCTION, FC1	27	18
70	1	HOSE ASSY-PUMP SUCTION, FC2	29	19
71	1	HOSE ASSY-CASE DRAIN,FC1	14	14
72	1	HOSE ASSY-CASE DRAIN,FC2	13	13
73	1	CHECK VALVE-RAT SUCTION	N/A	N/A
74	1	MANIFOLD-ACCUMULATOR	3	3
75	1	CHECK VALVE-CASE DRAIN	< 1	< 1
76	1	MANIFOLD-SUCTION DISCONNECT		
77	1	HOSE ASSY-AILERON PRESSURE	3	3
78	1	HOSE ASSY-AILERON RETURN	3	3
79	1	HOSE ASSY-AILERON RETURN	5	5
80	1	HOSE ASSY-AILERON PRESSURE	5	5
81	1	HOSE ASSY-AILERON PRESSURE	3	3

Table E-2. Component Volume Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
82	1	HOSE ASSY-AILERON RETURN	3	3
83	1	HOSE ASSY-AILERON RETURN	4	4
84	1	HOSE ASSY-AILERON PRESSURE	5	5
85	1	SELECTOR VALVE-L.E. FLAP	23	
101	2	AILERON ACTUATOR	206	101
102	2	SPOILER ACTUATOR	136	106
103	1	RUDDER ACTUATOR	106	53
104	2	UHT ACTUATOR	446	286
105	1	ROLL FEEL ACTUATOR	77	24
106	3	AFCS ACTUATOR	239	195
107	1	SPEED BRAKE ACTUATOR	658	334
108	8	LEADING EDGE FLAP ACTUATOR	47	26
109	1	RUDDER SERVO VALVE	185	170

*See Figure 3

N/A = Not Applicable

Table E-3. 3000 PSI Plumbing Weight/Volume Breakdown

SUBSYSTEM	TUBING WT DRY	OIL WEIGHT	FITTING WEIGHT	LINE VOLUME
PRESSURE LINES				
POWER GENERATION	11.93	3.50	5.23	157
POWER TRANSMISSION	15.90	4.77	7.14	212
UHT	3.65	1.02	1.02	43
RUDDER	1.11	.28	1.50	13
AILERON	2.72	.69	.73	32
SPOILER	.75	.19	.64	9
ROLL FEEL	.29	.04	.18	3
YAW AFCS	.25	.06	.27	3
ROLL AFCS	.32	.08	.41	4
PITCH AFCS	.07	.02	.14	1
SPEED BRAKE	2.82	1.07	2.24	45
LEADING EDGE FLAP	8.58	2.15	3.67	100
TOTALS	48.39 LB	13.87 LB	23.17 LB	622 IN^3
RETURN & SUCTION LINES				
POWER GENERATION	9.90	6.47	5.02	262
POWER TRANSMISSION	10.86	5.80	4.73	247
UHT	2.58	1.03	.76	44
RUDDER	.27	.12	.36	7
AILERON	2.34	.74	.73	33
SPOILER	.70	.21	.64	9
ROLL FEEL	.22	.07	.21	3
YAW AFCS	.09	.03	.15	2
ROLL AFCS	.14	.07	.21	4
PITCH AFCS	.04	.02	.11	1
SPEED BRAKE	.06	.27	.49	4
LEADING EDGE FLAP	.19	.09	.02	5
TOTALS	27.39 LB	14.92 LB	13.43 LB	621 IN^3

Table E-4. 8000 PSI Plumbing Weight/Volume Breakdown

SUBSYSTEM	TUBING WT DRY	OIL WEIGHT	FITTING WEIGHT	LINE VOLUME
PRESSURE LINES				
POWER GENERATION	4.18	1.35	1.55	70
POWER TRANSMISSION	5.68	1.84	1.43	95
UHT	1.24	.39	.24	21
RUDDER	.45	.14	.23	7
AILERON	1.12	.34	.25	18
SPOILER	.58	.15	.30	49
ROLL FEEL	.31	.09	.20	22
YAW AFCS	.10	.03	.04	2
ROLL AFCS	.13	.04	.06	2
PITCH AFCS	.03	.01	.02	1
SPEED BRAKE	1.06	.34	.38	17
LEADING EDGE FLAP	3.72	1.14	1.46	87
TOTALS	18.60 LB	5.86 LB	6.16 LB	391 IN^3
RETURN & SUCTION LINES				
POWER GENERATION	3.65	2.60	2.52	120
POWER TRANSMISSION	4.14	2.55	1.70	112
UHT	1.01	.42	.24	20
RUDDER	.24	.07	.14	4
AILERON	1.15	.35	.25	19
SPOILER	.48	.16	.30	49
ROLL FEEL	.25	.11	.20	22
YAW AFCS	.07	.02	.06	1
ROLL AFCS	.13	.04	.08	2
PITCH AFCS	.03	.01	.04	1
SPEED BRAKE	.09	.05	.05	2
LEADING EDGE FLAP	.32	.09	.02	3
TOTALS	11.56 LB	6.47 LB	5.60 LB	355 IN^3

TABLE E-5. Actuator Weight Summary

ACTUATOR		EXISTING WEIGHT (REF)	EQUIVALENT 3000 PSI SYSTEM	LHS SYSTEM	WEIGHT REDUCTION
SPOILER	(2)	11.48	16.35 *	10.75	5.60
AILERON	(2)	8.75	16.35 *	15.41	.94
ROLL FEEL	(1)	6.58	11.64 *	9.12	2.52
AFCS	(3)	15.79	15.79	14.95	.84
UHT	(2)	34.78	33.80 *	25.35	8.45
RUDDER	(1)	7.63	8.55 *	6.40	2.15
RUDDER VALVE	(1)	1.70	3.09 *	2.86	.23
SPEED BR.	(1)	46.41	46.41	43.93	2.48
L.E. FLAP	(8)	6.73	6.73	5.30	1.43
TOTALS			303.90 LB	252.58 LB	51.32 LB

*STEEL BARREL OR HOUSING

TABLE E-6. Subsystem Weight/Volume Breakdown

WEIGHT SUMMARY

SUBSYSTEM	3000 PSI	8000 PSI	REDUCTION
POWER GENERATION	201.34	154.15	47.19
DISTRIBUTION SYSTEM	51.69	18.84	32.85
UHT	84.03	56.62	27.41
RUDDER	15.83	10.86	4.97
AILERON	47.15	40.58	6.57
SPOILER	42.08	24.39	17.69
ROLL FEEL	15.58	10.34	5.24
YAW AFCS	17.44	17.10	.34
ROLL AFCS	17.79	17.26	.53
PITCH AFCS	16.95	16.92	.03
SPEED BRAKE	65.85	52.89	12.96
LEADING EDGE FLAP	79.59	53.73	25.86
TOTALS	655.32 LB	473.68 LB	181.64 LB

VOLUME SUMMARY

SUBSYSTEM	3000 PSI	8000 PSI	REDUCTION
POWER GENERATION	3237	2081	1156
DISTRIBUTION SYSTEM	582	263	319
UHT	989	619	370
RUDDER	323	238	85
AILERON	440	284	156
SPOILER	364	314	50
ROLL FEEL	106	70	36
YAW AFCS	257	212	45
ROLL AFCS	261	214	47
PITCH AFCS	253	210	43
SPEED BRAKE	803	420	377
LEADING EDGE FLAP	558	282	276
TOTALS	8173 IN^3	5207 IN^3	2960 IN^3

TABLE E-7. Major Elements Weight Summary

ITEM	EQUIVALENT 3000 PSI SYSTEM	PERCENT OF SYS.WT.	LHS SYSTEM	PERCENT RED. IN COMP.WT.
PUMP	29.80	4.5	37.00	+24.2
RESERVOIR	50.56	8.2	48.80	- 3.5
ACTUATORS	303.90	46.2	252.58	-16.9
TUBING	75.90	11.6	30.16	-60.3
OIL	76.04	11.6	38.91	-48.8
FITTINGS	36.89	5.6	11.76	-68.1
MISC. COMP.	82.23	12.3	53.99	-34.3
TOTALS	655.32 LB	100%	473.20 LB	

TABLE E-8. Configuration Adjustments Weight Summary

	EQUIVALENT 3000 PSI SYSTEM	LHS SYSTEM
BASIC SYSTEM	655.3 LB	473.2 LB
CONFIGURATION ADJUSTMENTS		
RESERVOIR	- 7.3	-11.6
UHT ACTUATOR	0	- 2.0
CASTINGS/FORGINGS	0	- 6.3
SHRINK-FIT VALVES (AIL, RUD, UHT, ACTRS)	0	-12.3
INCREASED PUMP SPEED	- 3.6	- 9.7
TOTALS	- 10.9 LB	41.9 LB
ADJUSTED SYSTEM WT.	644.4 LB	431.3 LB

APPENDIX F

FAILURE MODES AND EFFECTS ANALYSIS

CONTENTS

FAILURE MODES AND EFFECT ANALYSIS OF A LIGHTWEIGHT HYDRAULIC SYSTEM

System Definition - This FMEA has been developed for a Lightweight Hydraulic System designed for installation in an A-7E aircraft. The schematic diagrams upon which this analysis is based are presented in Figures F-1 through F-14. The FMEA is presented in Table F-1.

Failure Effects Definition - In performing the FMEA of the Lightweight Hydraulic System, the effects of each failure mode are evaluated with respect to the function of the related individual hardware item. These individual hardware failure effects are then related in sequence to the total LHS system. The effects of any failure will be limited to the impact on the hydraulic component, subsystem, or system. The effects as related to the intended function of the subsystem which the hydraulic system services, or the effects on the ultimate performance of the A-7 airplane are not a part of the LHS evaluation. Therefore, the following failure definitions apply to the hydraulic functions:

Aircraft Hydraulic System - The loss of hydraulic power from both FC-1 and FC-2 power systems. Where the end effects states "Loss of System Fluid," it is implied that this is a loss of the respective power system.

Hydraulic Subsystem - The inability of the subsystem to function within specified performance due to a hydraulic component or part discrepancy.

Component/Part - The inability of the component/part to perform its intended function within specified limits.

Subsystem Identification - To maintain a systematic approach to referencing failure modes throughout the analysis the following failure mode identification system was used.

XX.YYY-ZZ

where XX identifies the subsystem as follows:

01 FC-1 power

02 FC-2 power

03 speed brakes

04 roll feel isolation

05 autopilot system

06 aileron and spoiler

07 leading edge flaps

10 rudder

11 unit horizontal tail

YYY identifies the component from the system schematic and ZZ identifies the failure mode sequence.

Malfunction Codes - The most likely malfunction codes as recorded by maintenance personnel if a failure were to occur are listed on the work sheets in accordance with OPNAVINST 4790.2C, "Malfunction Description Codes."

Severity Levels - Severity levels of criticality will be defined as follows:

- Level I, Catastrophic: Complete loss of hydraulic power or functional capability of an actuator assembly
- Level II, Critical: Degradation of hydraulic power or actuator performance or any failure resulting in personal injury to maintenance personnel
- Level III, Major: Degradation of component performance resulting in negligible effect to total LHS performance and resulting in maintenance action at organization level
- Level IV, Minor: No effect on total LHS performance and no component removal required

Failure Rate Definitions - Failure rates were extrapolated from 3M data for the A-7E aircraft, using leak path comparisons, laboratory experience, and other design data as a basis for the projection. All failure rates presented are expressed in terms of failure per million flight hours. The failure rate definitions used on the FMEA format are defined as follows:

λ_p is the basic failure rate of the component.

α is the fractional contribution the failure mode contributes to the total component failure rate.

β is the conditional probability factor for the failure end effect occurring, given that the failure mode has occurred.

λ_o is the operational failure rate, or the product of λ_p, α and β.

Part Identification List - Use the list provided below and Figures F-1 through F-5 to locate parts in the pump.

ITEM CODE	DESCRIPTION OF ITEM
A	Coupling, Drive (570830)
A1	Ring, Coupling Shaft Retaining (Retainer "C" Ring) (570831)
A2	Packing, Coupling to Cylinder Block (395831)
B	Yoke, Pin & Inserts Subassembly (570809)
B1	Yoke, (363776)
B2	Pin (248774)
B3	Insert (Helicoil 33537)
B4	Plate, Piston Shoe Bearing (570845)
C	Rotating Group Assembly
C1	Block, Cylinder (570832)
C2	Bearing-Thrust (Bearing, Ball Annular 211606)
C3	Plate, Balance Subassembly (570821)
C3.1	Plate, Hold Down (570824)
C3.2	Plate, Balance (570822)
C3.3	Plate, Spacer (570823)
C3.4	Rivet, Countersunk Head (580511)
C4	Spring, Cylinder Block Hold Down (570833)
D	Piston Shoe Assembly (9) (570825)
D1	Piston (9) (570827)
D2	Shoe (9) (570828)
F	Plate, Hold Down, Retainer (570844)
F1	Screws (8) (224945)
G	Housing, Pins & Inserts Assembly (570805)
G1	Housing
G2	Inserts, Housing, Helicoil (7) (185993)
G3	Pin, Housing, Locating for Mating Flange (2) (248819)
G4	Packing, Valve Block to Housing (395958)
G5	Screw, Valve Block to Housing Assembly (7) (580555)
G6	Washer, Screw, Valve Block to Housing Assy(7) (32261)
G7	Piston, Yoke Control (Actuator, Piston, 570841)
G8	Piston, Spring Return, yoke control (570839)
G9	Spring, Yoke Control (570840)
G10	Seat, Spring, Yoke Control (570838)
H	Transfer Tube, Yoke Control (570842)
H1	Packing, Transfer Tube, Yoke Control (395824)
H2	Ring, Back-Up, Transfer Tube, Yoke Control (197567)
H3	Packing, Transfer Tube to Housing (395825)
H4	Ring, Back-Up, Transfer Tube to Housing (197568)
J	Bearing, Yoke (2) (312173)
K	Bearings Roller, Cylinder Block (577738)

ITEM CODE	DESCRIPTION OF ITEM
L	Spacer, Bearing (570837)
M	Flange, Mating, Pins & Inserts Assembly (570846)
M1	Flange, Mating (570846)
M2	Insert, Screw, Mating Flange, (Helicoil) (6) (429318)
M3	Pin, Mating Flange, Locating for Mounting Flange (1) (248820)
M4	Packing, Mating Flange to Mounting Flange (395957)
M5	Packing, Housing to Mating Flange (395972)
M7	Screw, Mating Flange to Housing (10) (580555)
M8	Washer, Mating Flange to Housing Assembly (10) (32261)
N	Shaft Seal Assembly (570811)
N1	Spring, Toroidal, Shaft Seal (570813)
N2	Grommet, Shaft Seal (570815)
N3	Spacer, Shaft Seal (570814)
N4	Spring, Wave Shaft Seal (570816)
N5	Retainer, Shaft Seal (570812)
N6	Seal, Carbon (570817)
N7	Ring, Mating, Shaft Seal (Steel) (570829)
N8	Packing, Mating Flange to Mating Ring (395884)
P	Ring, Retaining Shaft Seal (570826)
P1	Screws, Shaft Seal Retaining (6) (224942)
P2	Washer, Screw, Shaft Sealing Retaining (6) (51903)
Q	Plate, Transfer (570835)
R	Tube-Transfer Assembly
R1	Tube Transfer (9) (570834)
R2	Packing, Transfer Tube (9) (395826)
R3	Ring, Back-Up, Transfer Tube (9) (197569)
S	Plate, Wafer (570836)
W	Block, Valve Assembly (570807)
W1	Insert, Valve Block, Helicoil (4) (185993)
W2	Pin, Valve Block, (248819)
W3	Screws, Outlet Connector Securing (4) (580554)
W4	Packing, Valve Block to Housing (395958)
W5	Plug, Fill and Drain, Housing (89276)
W6	Packing, Plug to Housing (396096)
W7	Lockwire, Fill and Drain Plug (48982)
X	Compensator Assembly
X1	Sleeve & Pilot Valve Subassembly (570818)
X1.1	Sleeve, Compensator (570820)
X1.2	Valve, Pilot Compensator (570819)
X2	Packing Valve Block to Sleeve (2) (395828)
X3	Ring, Back-Up, Valve to Sleeve (2) (197571)
X4	Adapter, Compensator Adjusting Screw (570849)
X5	Packing Valve Block to Adapter (395834)
X6	Guide, Spring, Compensator (570853)
X7	Spring, Compensator (570854)
X8	Seat, Spring, Compensator (570852)
X9	Screw, Adjusting, Pressure Control (570850)
X10	Packing, Adapter to Adjusting Screw (395832)
X11	Nut, Locking, Compensator (570851)

ITEM CODE	DESCRIPTION OF ITEM
Y	Adapter, Discharge (570843)
Y1	Packing, Discharge Adapter to Valve Block (395875)
Y2	Ring, Back-Up, Discharge Adapter to Valve Block (197596)
Z	Mounting Flange (570802
Z1	Clamp, Mating Flange to Mounting Flange (570802)
Z10	Plate, Rotation Indicator (344947)
Z11	Plate, Identification (56981)

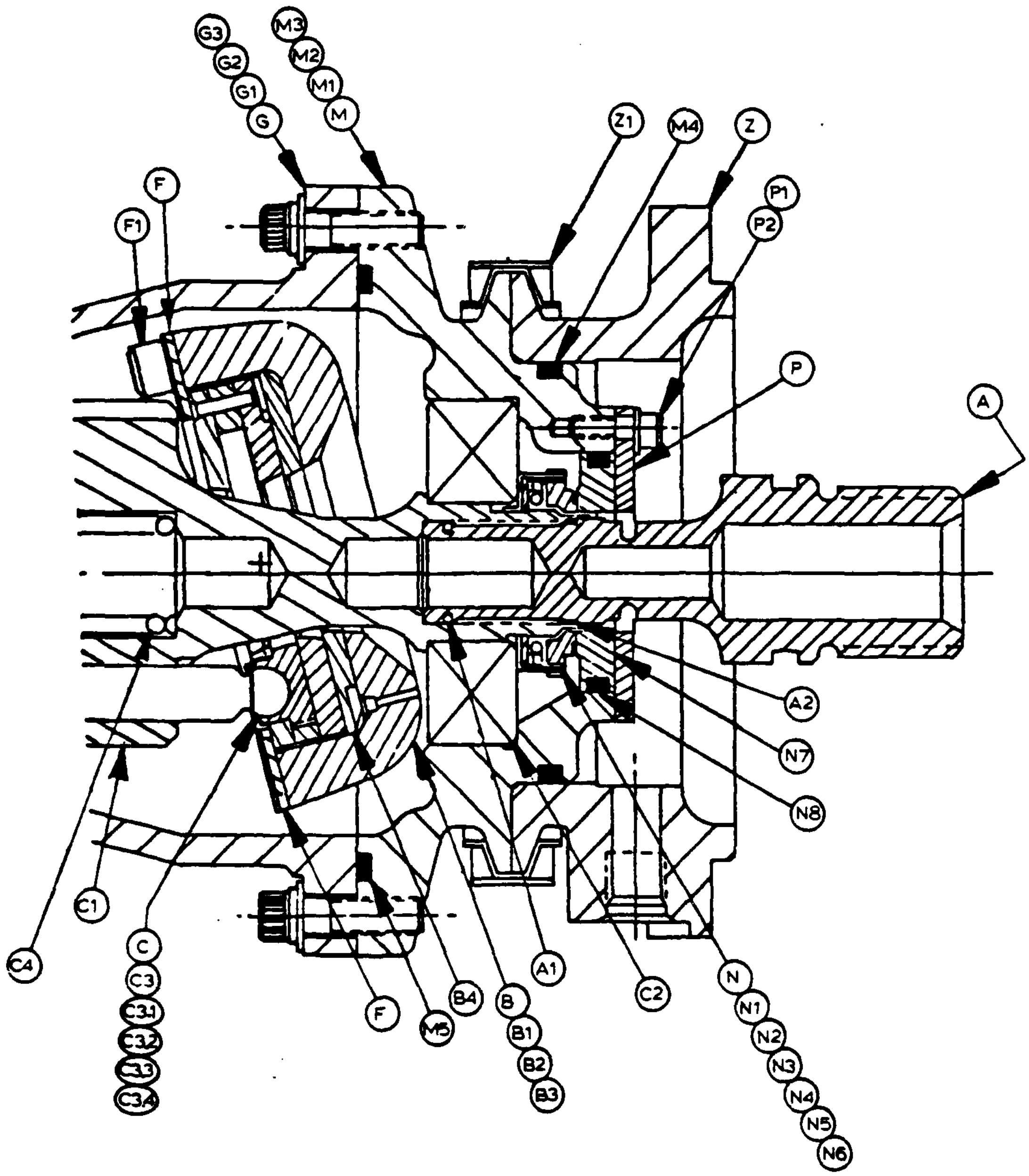


Figure F-1. Side View - Drive Shaft End of Pump Showing Coupling Shaft, Shaft Seal, and Yoke and Piston Detail

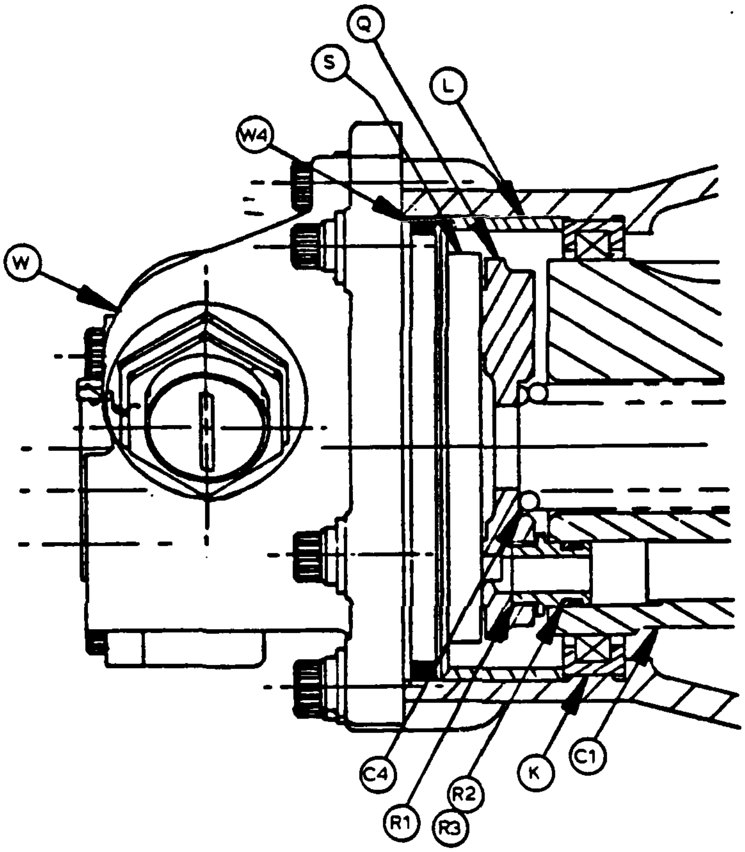


Figure F-2. Side View - Showing Transfer Tubes, Cylinder Block Bearing and Valve Block Assembly

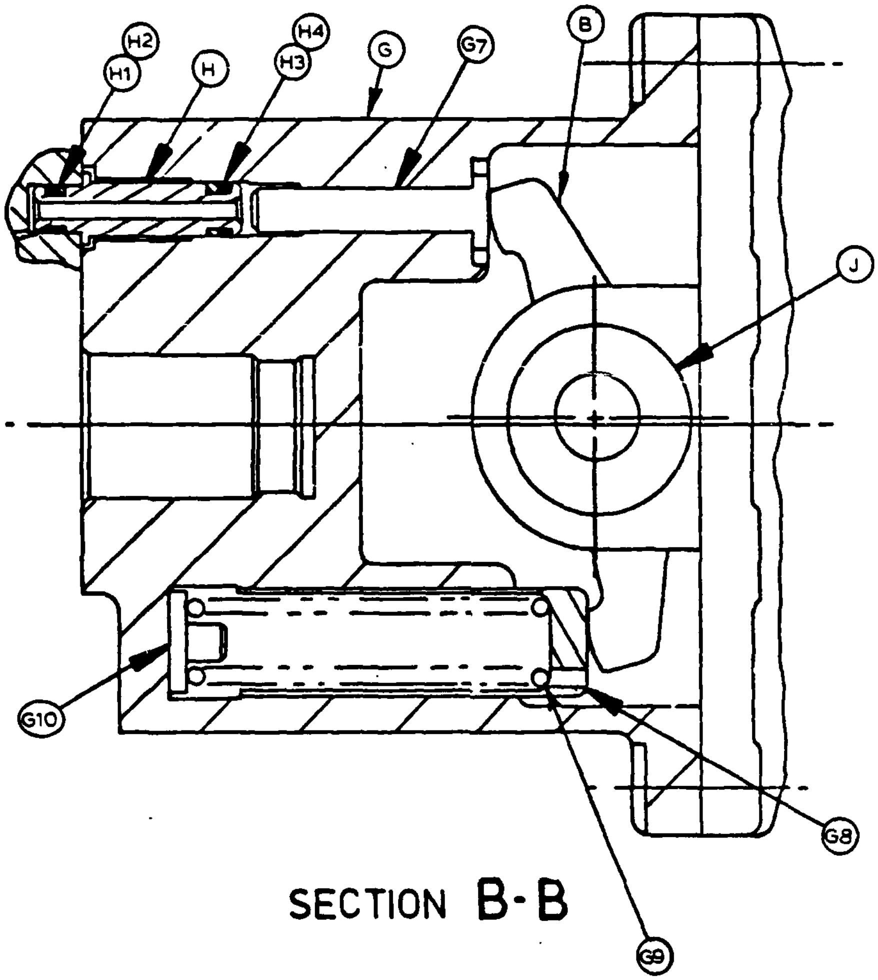


Figure F-3. Section B - Showing Detail of Yoke Positicn Control

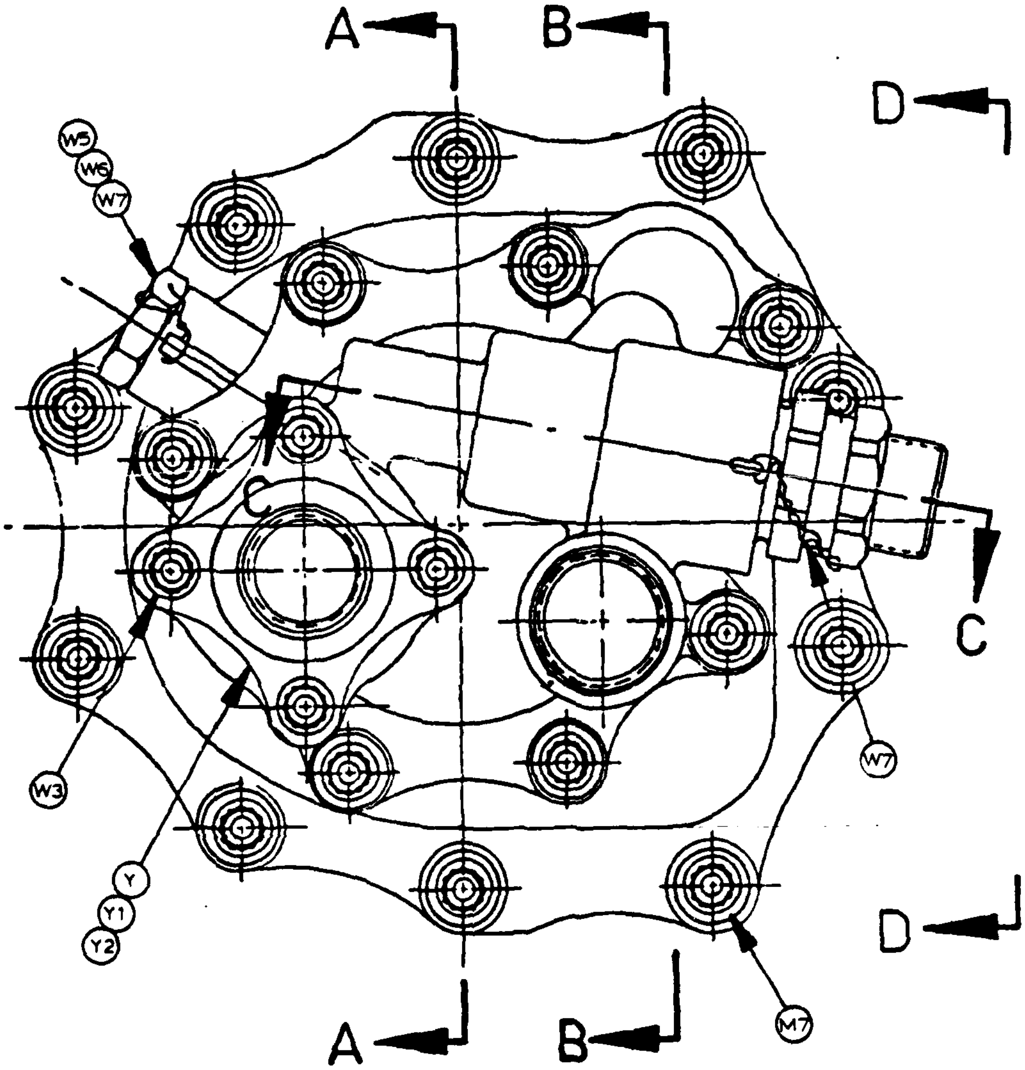


Figure F-4. End View of Pump, Showing Valve Block End, Hydraulic Connection Points and Section Views

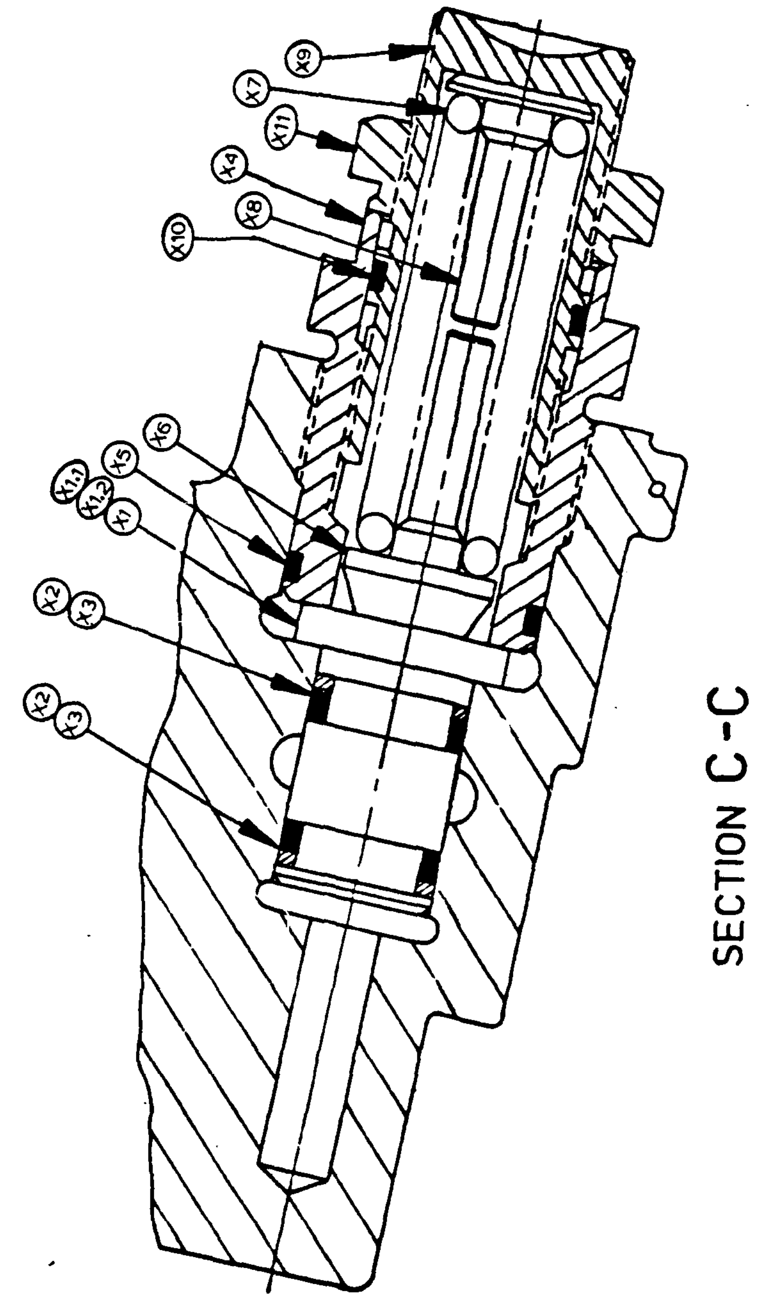


Figure F-5. Compensator Detail

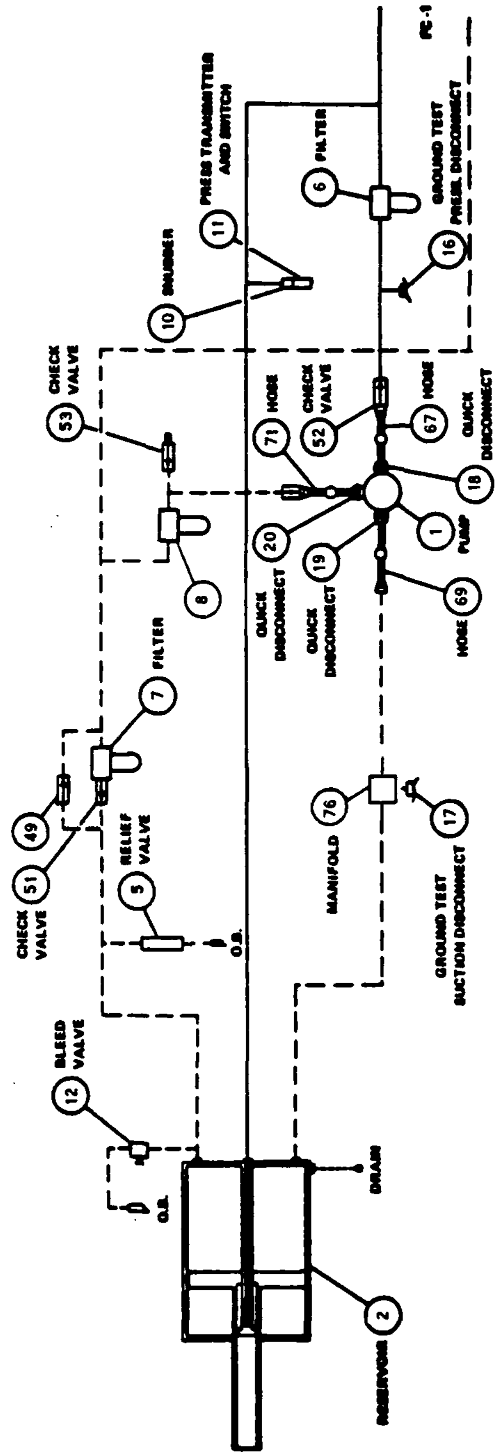


Figure F-6. FC-1 Power System

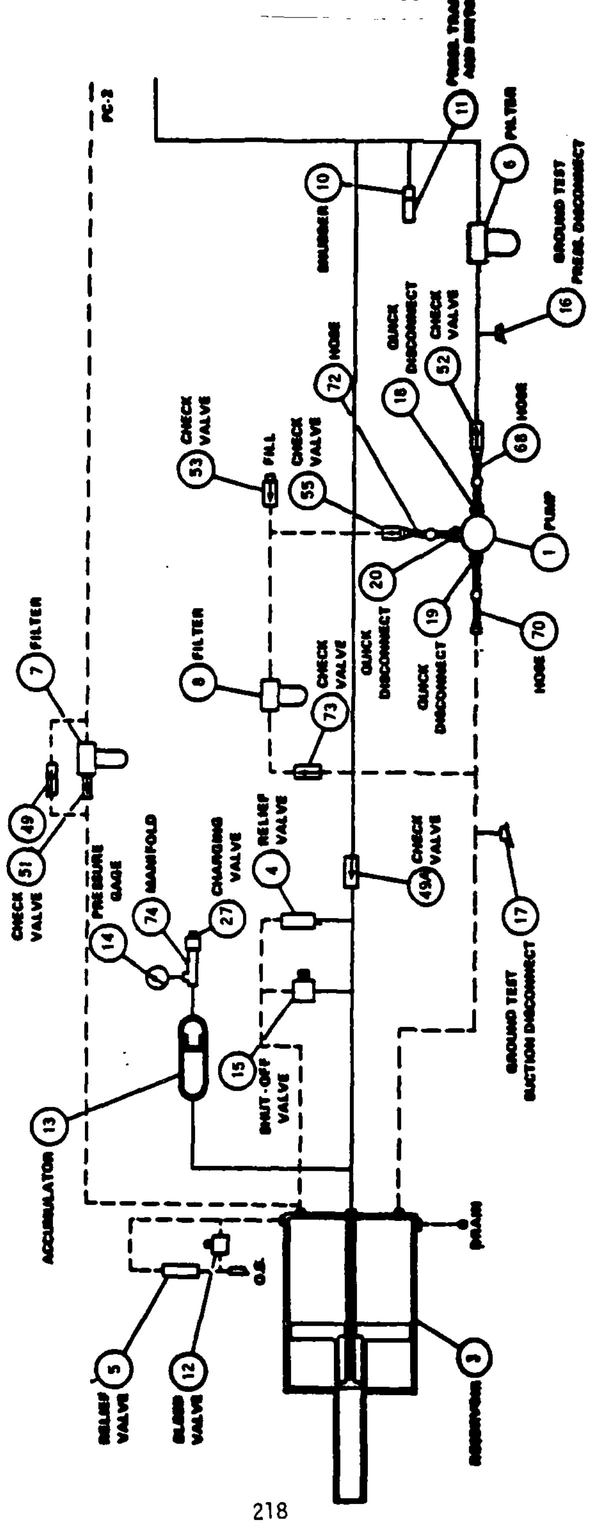


Figure F-7. FC-2 Power System

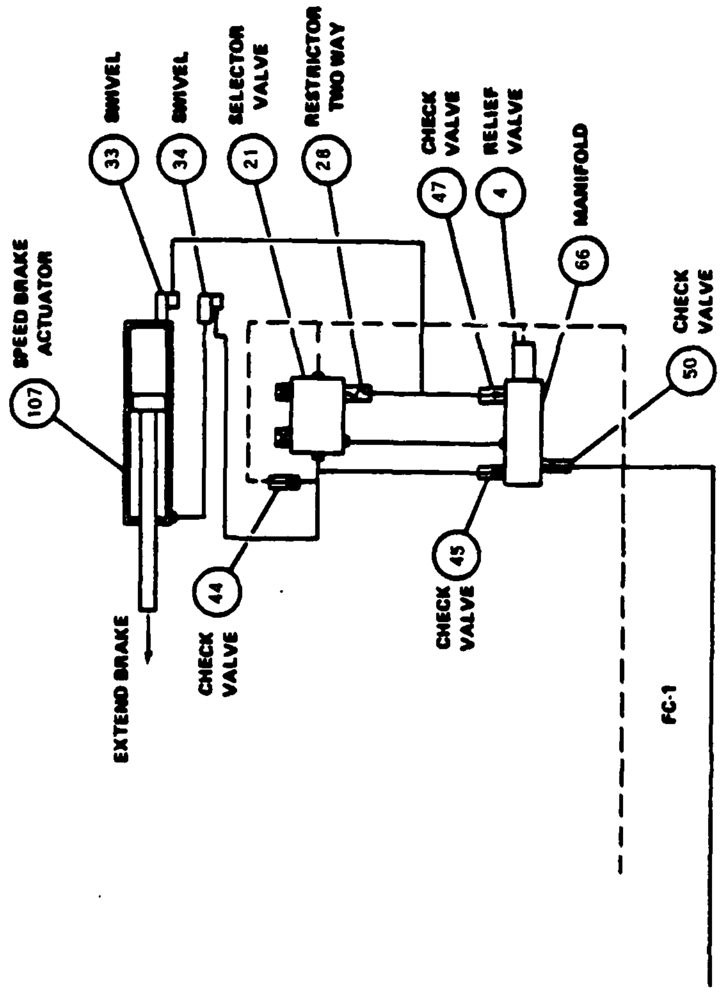


Figure F-8. Speed Brake

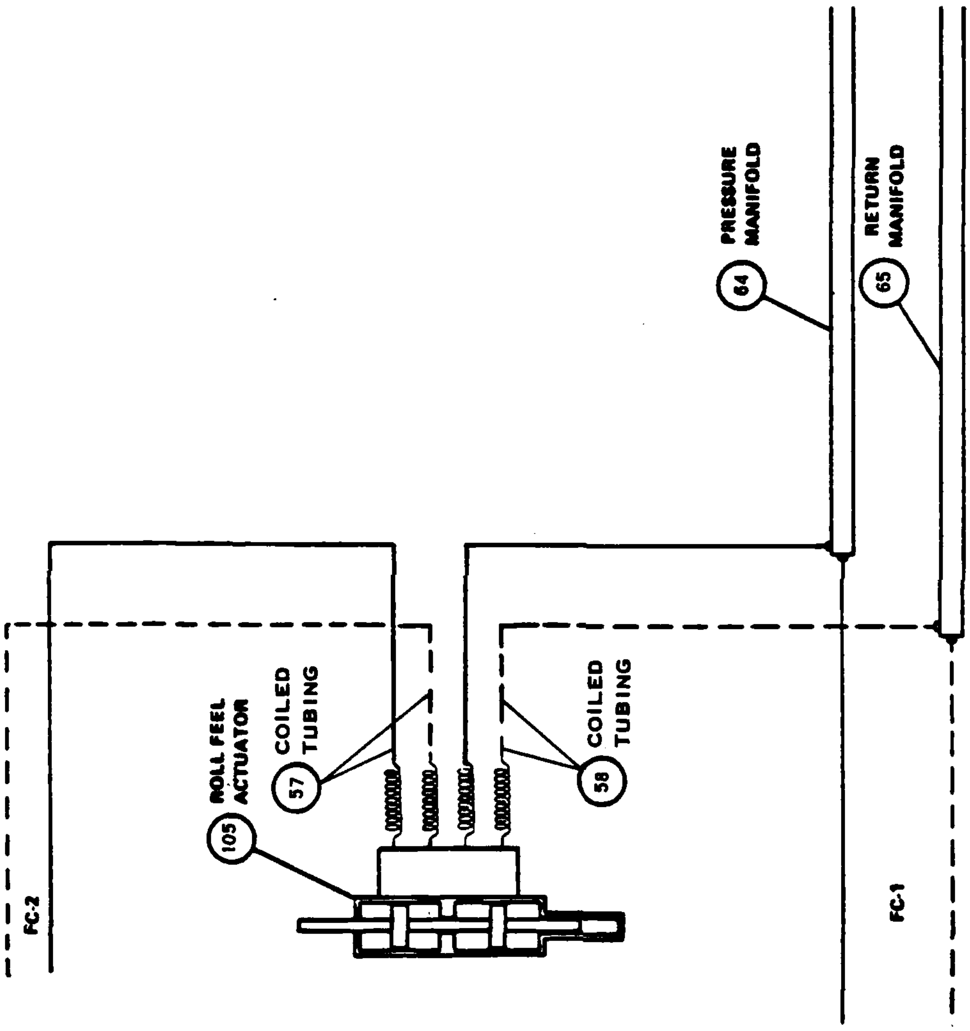


Figure F-9. Roll Feel Isolation

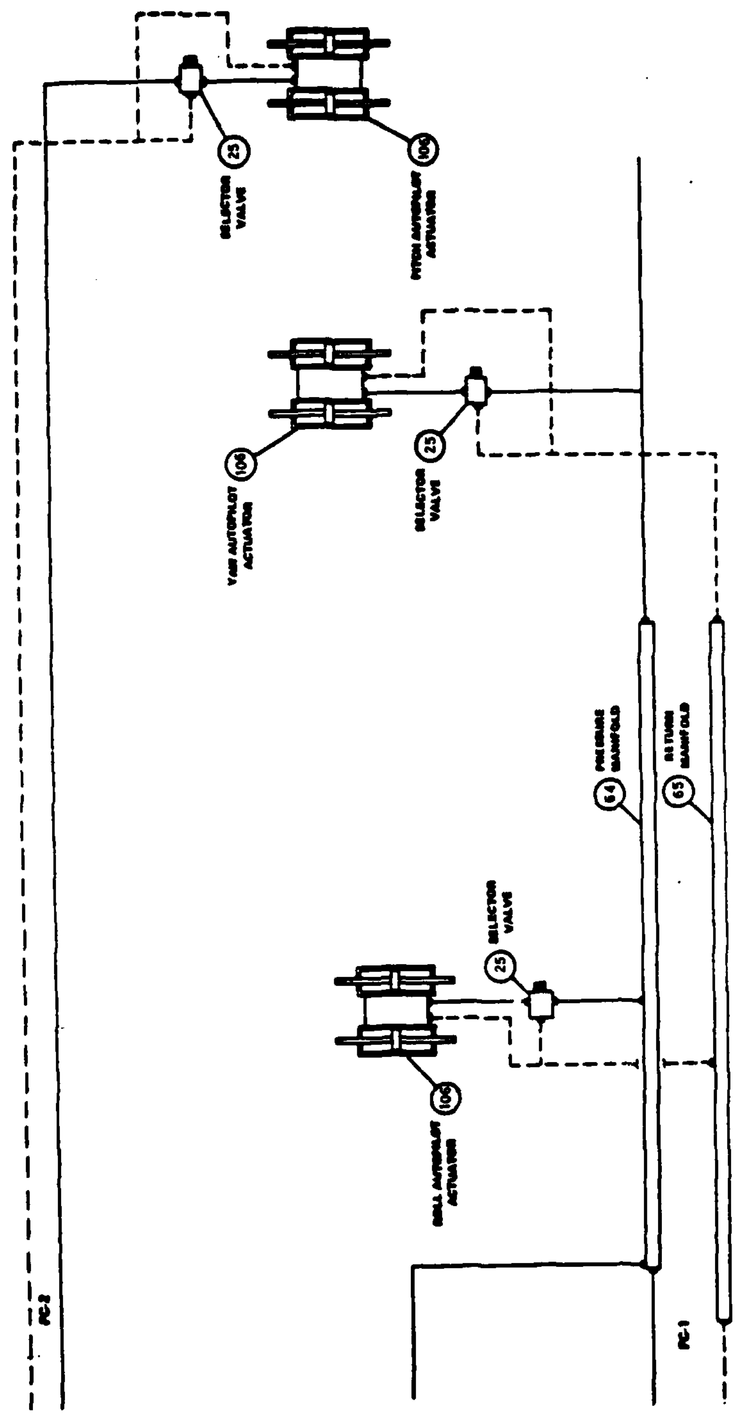


Figure F-10. Autopilot

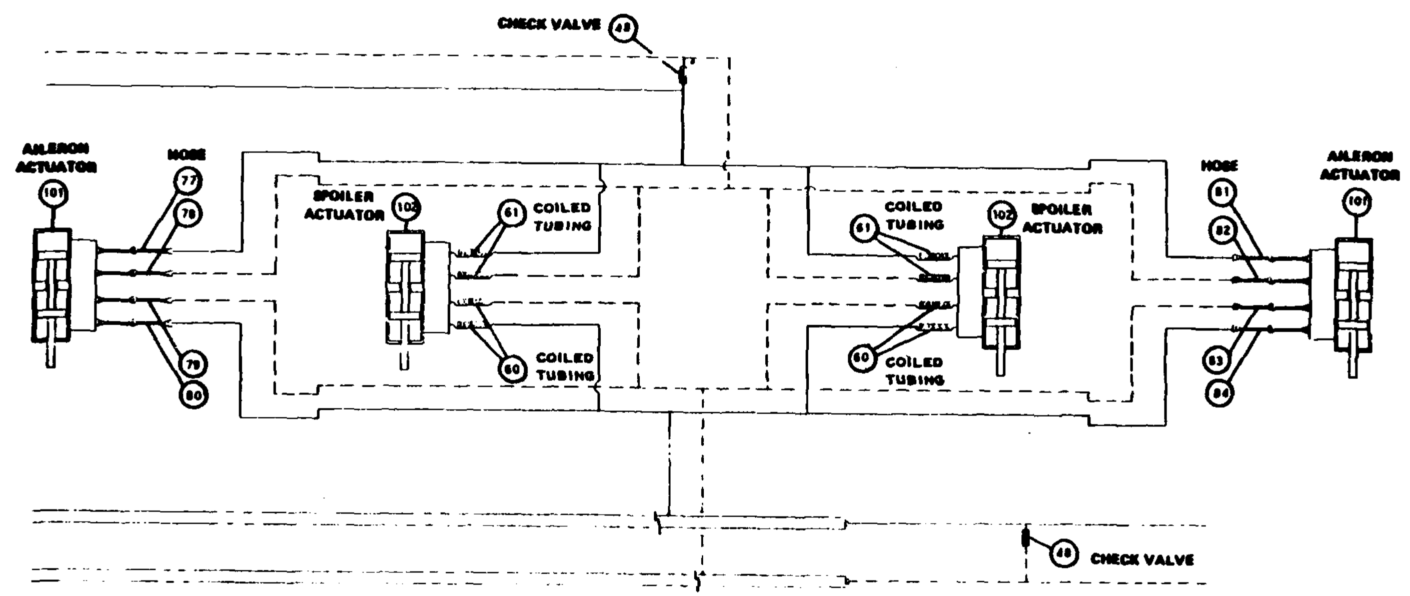


Figure F-11. Aileron and Spoiler

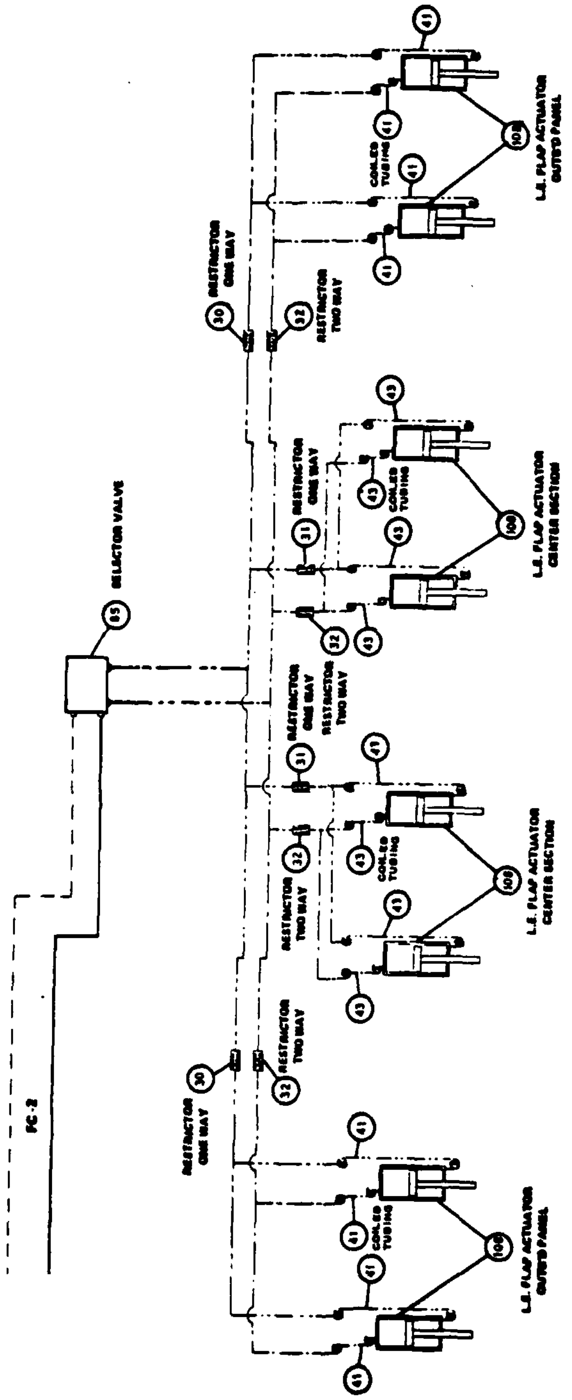


Figure F-12. Leading Edge Flaps

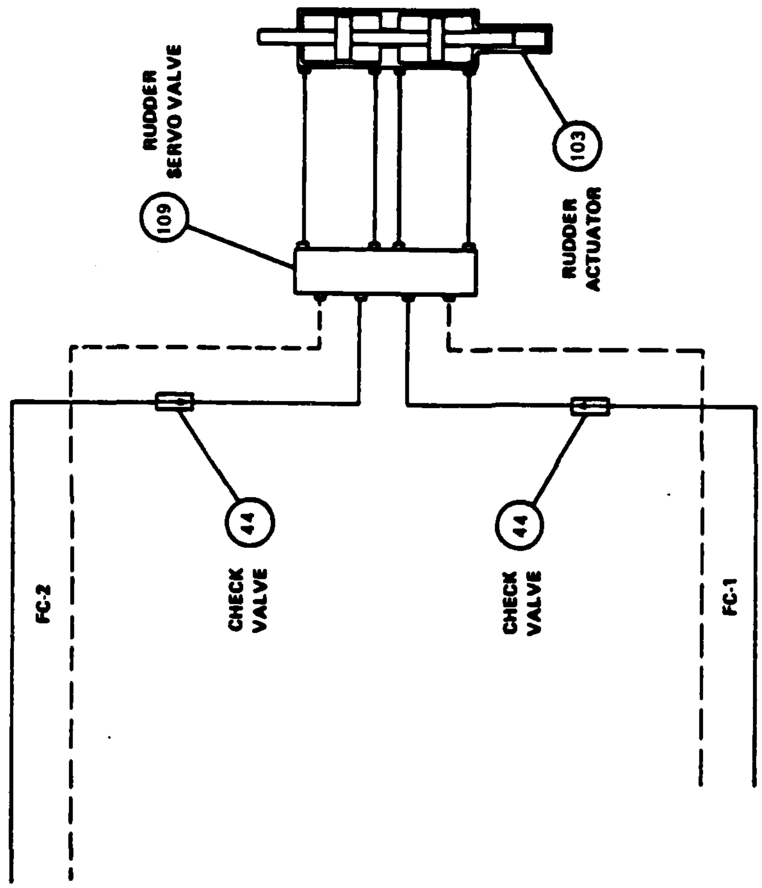


Figure F-13. Rudder

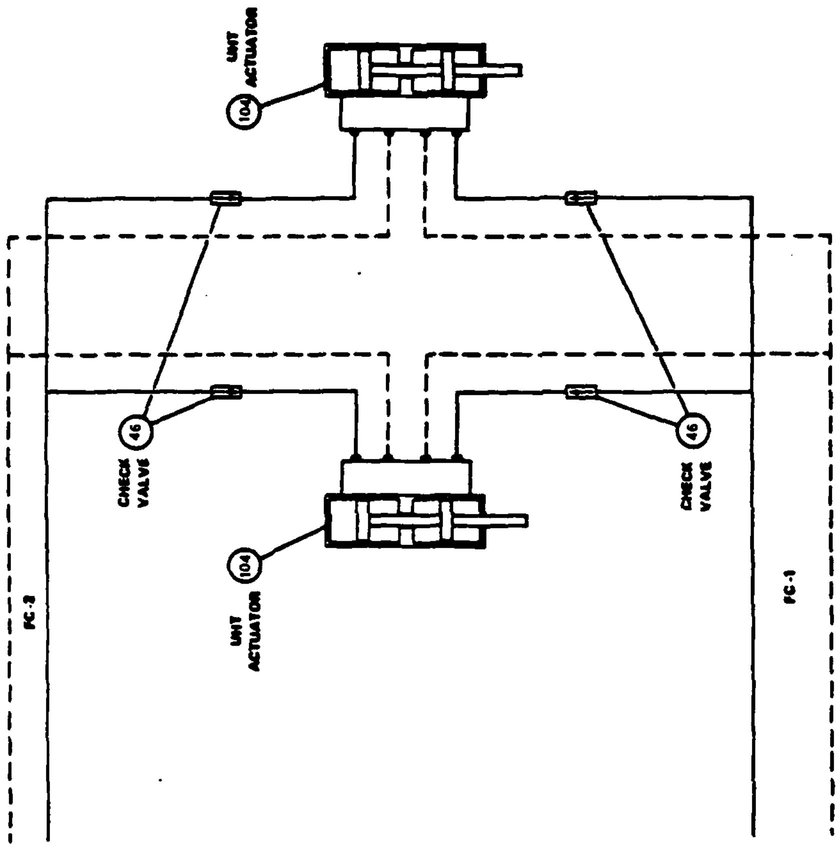


Figure F-14. Unit Horizontal Tail

TABLE F-1.

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
FC-1/FC-2 PUMP	PROVIDE SYSTEM FLUID UNDER PRESSURE	01.001-00 02.001-01	FAILS TO OPERATE SEE DETAIL PARTS ANALYSIS		LOSS OF PUMPING FUNCTION	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM		II				
COUPLING SHAFT	TRANSFER INPUT TORQUE TO DRIVE SHAFT	A-01	SPLINE WEAR	IMPROPER ALIGNMENT, LACK OF LUBE DURING INSTALLATION	WEAR DEBRIS/ SPLINE FREE-PLAY	POSSIBLE PUMP DAMAGE	PUMP REMOVAL	-----	070 242 020	II	65.47	0.80	1.00	52.38
		A-02	SHEAR AT LOW TORQUE	FATIGUE AT SHEAR SECTION, QUALITY CONTROL OF TOLERANCES AND MATERIALS	LOSS OF PUMPING FUNCTION	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 585	II		0.08	1.00	5.24
		A-03	FAILURE TO SHEAR	QUALITY CONTROL OF MATERIAL TOLERANCES	INTERNAL PUMP DAMAGE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374 525	II		0.08	1.00	5.04
COUPLING SHAFT RETAINING RING	RETAINS COUPLING SHAFT IN PLACE	A1-01	BROKEN	-----	INSTALLED - RING REMAINS CAPTIVE UNINSTALLED - SHAFT MAY SEPARATE FROM PUMP	NONE	PUMP REMOVAL	NONE	070	IV	0.03	1.00	0.00	0.00
YOKE	TRANSFERS LOAD FROM PRESSURE PLATE TO PINTLE BEARING AND YOKE CONTROL	B1-01	BENDING, FLEXIBILITY	INADEQUATE DESIGN FOR STIFFNESS, FATIGUE DUE TO STRESSES	INTERNAL LEAKAGE	UNSTABLE FC-1/FC-2 PRESSURE	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374 525	III	2.74	0.70	1.00	1.92
		B1-02	FRACTURE	FATIGUE	INTERNAL PUMP DAMAGE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II		0.30	1.00	0.82
PISTON SHOE BEARING PLATE	SUPPORTS A HYD. BEARING SURFACE FOR BALANCE PLATE/PISTON SHOE	B4-01	EXCESSIVE WEAR	LOADS EXCEEDS HYDRAULIC BEARING AND LUBE CAPABILITY	HEATING OF PLATE SURFACES, INCREASED FRICTION LOAD AND WEAR	INTERNAL LEAKAGE	FILTER CONTAMINATION	-----	185 372 900	IV	0.03	1.00	1.00	0.03

LMS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY λ_p	α	β	λ_o
CYLINDER BLOCK	TRANSFERS TORQUE OF COUPLING SHAFT TO ROTATION OF CYLINDERS; CAUSES PISTONS TO ORBIT & OSCILLATE IN BLOCK; CARRIES CENTRIFUGAL FORCE OF PISTONS; DIRECTS HYDRAULIC FLOW FROM PISTON MOTION TO TRANSFER TUBES	C1-01	PISTON SEIZURE	CONTAMINATION OF FLUID; OVER HEATING; LOSS OF LUBRICATION	SHEARING OF COUPLING SHAFT; INTERNAL PUMP DESTRUCTION	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374 900 185 008 135	II	20.09	0.41	1.00	8.24
		C1-02	BROKEN OR CRACKED CYLINDER BLOCK	FATIGUE AT SECTION BETWEEN SPLINE & BEARING, WEB BETWEEN BORES AND FROM SIDE THRUST BENDING LOADS	PUMP SELF DESTRUCTS	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374 070	II		0.08	1.00	1.61
		C1-03	INTERNAL SPLINE WEAR	LACK OF LUBRICATION; NORMAL WEAR	FREE-PLAY AT SPLINE	-----	-----	-----	242 374 070	II		0.49	1.00	9.84
		C1-04	WEAR AT TRANSFER TUBES	ALIGNMENT MOTION	INTERNAL LEAKAGE	FLUCTUATION OF SYSTEM PRESSURE; PUMP VIBRATION	COCKPIT PRESSURE INDICATOR	-----	525 037	III		0.01	1.00	0.20
		C1-05	WEAR AT SHAFT SEAL	DAMAGED SEAL; DAMAGED SHAFT	LEAKAGE	HIGH LEAK RATE MAY CAUSE LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	381	III		0.01	0.05	0.01
THRUST BEARING	PROVIDES LOW FRICTION FOR CYL. BLOCK ROTATION; CARRIES BEND & THRUST LOADS	C2-01	SPALLING OF RACES OR ROLLERS	OVERSTRESS; LACK OF LUBRICATION	INCREASE IN BEARING FRICTION	BEARING SELF DESTRUCTS	METAL IN FILTER	FILTERS	374 185 372	IV	10.90	1.00	1.00	10.90
BALANCE PLATE ASSEMBLY	CONVERTS INDIVIDUAL PISTON FORCES INTO COMPOSITE FORCE & BEARING SURFACE; TRANSMITTED TO YOKE ASSEMBLY	C3-01	FRACTURE OF PISTON SHOE HOLD DOWN	PISTON SEIZURE	PUMP FAILURE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II	9.52	0.03	0.02	----
		C3-02	FRACTURE OF PISTON SHOE BALANCE PLATE	FATIGUE; OVERHEAT STRESS	WEAR OF RUBBING SHOE SURFACE	REMOVAL BECAUSE OF WEAR INDICATIONS	FILTER CHECKS	-----	185 372	IV		0.69	1.00	6.57
		C3-03	BALANCE PLATE ASSEMBLY RIVETS FAIL IN TENSION	FATIGUE STRESSES	DISASSEMBLY AND PUMP FAILURE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II		0.28	1.00	2.67

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
CYLINDER BLOCK HOLD DOWN SPRING	HOLDS CYLINDER BLOCK AGAINST VALVE PLATE	C4-01	WEAKENS OR BREAKS	FATIGUE	NONE WHILE OPERATING; BLOCK LIFTS DURING START-UP	INTERNAL LEAKAGE ON START-UP	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II	1.64	1.00	1.00	1.64
PISTON (9)	LINEAR MOTION IN CYLINDER BLOCK RESULTS IN PUMPING OF FLUID	D1-01	PISTON SEIZES IN CYLINDER BLOCK	CAVITATION OF FLUID AND LOSS OF LUBRICATION	SEVERE STRESS ON YOKE AND FAILURE OF PUMPING ACTION	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II	6.14	1.00	1.00	6.14
SHOE (9)	TRANSMITS FORCES APPLIED BY YOKE TO PISTON	D2-01	WEAR AT COINED SPHERICAL JOINT	EXCESSIVE COMPRESSION AND TENSION LOADS	NOISY PUMP; EXCESSIVE WEAR CAUSES SEPARATION OF JOINT AND PUMP FAILURE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR; NOISY PUMP	FC-1/FC-2 SUBSYSTEM	242 374 008	III	41.36	0.75	0.80	24.82
		D2-02	CRACKED OR BROKEN AT COINED JOINT	FATIGUE	DISASSEMBLY OF PISTON FROM SHOE	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II		0.25	1.00	10.34
RETAINER HOLD DOWN PLATE	HOLDS BALANCE PLATE SUB-ASSY. IN PLACE	F-01	FATIGUE FRACTURE	OVERSTRESS FROM PISTON SEIZURE OR LOADS FROM LOW INTAKE PRESSURE	DESTRUCTION OF YOKE ASSEMBLY	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II	3.29	0.97	1.00	3.19
		F-02	FRACTURE OF RETAINER SCREWS	FATIGUE; OVERSTRESS CAUSED BY PISTON SEIZURE	FAILURE TO HOLD RETAINER - END OF PUMPING ACTION	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	II		0.03	0.05	0.004
HOUSING	PROVIDES STRUCTURE ENCLOSING PUMP; SUPPORTS CYLINDER BLOCK BEARING & VALVE BLOCK	G1-01	CRACKED OR BROKEN	FATIGUE FROM STRESS OF CASE PRESSURE, ROTATING PARTS, HYDRAULIC FORCES, & MATERIAL DEFECTS	CASE LEAK; ADJUSTMENTS OUT	IMPROPER PRESSURE, LOSS OF FLUID, AND SUBSYSTEM CAPABILITY	COCKPIT PRESSURE INDICATOR; VISUAL INSPECTION	FC-1/FC-2 SUBSYSTEM	242 374 381 127	III	1.36	1.00	0.01	0.01
VALVE BLOCK TO HOUSING FACING	SEALS JOINT BETWEEN VALVE BLOCK & HOUSING	G4-01	LEAKS	WEAR OF "O" RING FROM PRESSURE CYCLING, HIGH TEMPERATURE PERMANENT SET	JOINT LEAKS	MAINTENANCE ACTION	VISUAL INSPECTION	-----	381	IV	0.04	1.00	1.00	0.04
YOKE CONTROL PISTON	POSITIONS ANGLE OF YOKE	G7-01	WEAR	PISTON MOVEMENT	INCREASED FLUID LEAKAGE PAST PISTON	HIGHER THAN NORMAL PRESSURE	COCKPIT PRESSURE INDICATOR	COMPENSATOR ADJUSTMENTS	525 127	IV	5.46	1.00	1.00	5.46

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
YOKE CONTROL SPRING RETURN PISTON	CONTAINS YOKE SPRING; CONTROLS MAXIMUM ANGLE OF YOKE	68-01	PISTON RUBS AGAINST SPRING	MFG. TOLERANCE	CHANGE OF SPRING RATE	SUBSYSTEM PRESSURE FLUCTUATES	COCKPIT PRESSURE INDICATOR	-----	525 374	IV	1.45	0.50	1.00	0.72
		68-02	PISTON BINDS IN BORE OF HOUSING	SIDE LOAD FROM YOKE; HIGH TEMP.	INTERMITTENT OVER PRESSURE	SUBSYSTEM PRESSURE FLUCTUATES	COCKPIT PRESSURE INDICATOR	-----	525 374	IV		0.50	1.00	0.72
YOKE CONTROL SPRING	FORCES YOKE TO MAXIMUM ANGLE	69-01	SPRING SAG OR BREAK	FATIGUE	LOW PUMP PRESSURE	LOW SUBSYSTEM PRESSURE	COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	IV	40.92	1.00	1.00	40.92
YOKE CONTROL TRANSFER TUBE	TRANSFERS HIGH PRESSURE FLUID FROM VALVE BLOCK TO HOUSING	H-01	SEAL LEAKAGE AT EACH END OF TRANSFER TUBE	WEAR FROM PRESSURE FLUCTUATIONS	INTERNAL LEAKAGE	NONE	NONE	NONE	381	IV	0.21	1.00	---	----
PINTLE BEARING (2)	BEARING FOR YOKE ROTATION	J-01	SPALLING OF RACES OR ROLLERS	OVERSTRESSED (UNDER DESIGNED APPLICATION); NORMAL WEAR	ERRATIC FLOW AND PRESSURE CONTROL	ERRATIC SUBSYSTEM PRESSURE; METAL IN FILTER	COCKPIT PRESSURE INDICATOR	PUMP DESIGN CAPABILITIES SHOULD EXCEED SYSTEM REQMTS.	525 637 372 165	III	0.11	1.00	1.00	0.11
CYLINDER BLOCK RADIAL BEARING	CONTROL CYLINDER BLOCK POSITION DURING ROTATION	K-01	FRICTION INCREASE	FATIGUE OF BEARING ELEMENTS	INTERNAL LEAKAGE BETWEEN CYLINDER BLOCK AND VALVE PLATE	METAL IN FILTERS; OVERHEATING	FILTER CHECKS	PUMP DESIGN CAPABILITIES SHOULD EXCEED SYSTEM REQMTS.	185 372	III	10.91	1.00	1.00	10.91
MATING FLANGE ASSEMBLY	SUPPORTS PINTLE BEARINGS, THRUST BEARING, SHAFT SEAL, AND IS CLOSURE OF PUMP CASE	M-01	BROKEN OR CRACKED MATING FLANGE	FATIGUE OR EXCESSIVE EXTERNAL LOADS	FLUID LEAKAGE OR MISALIGNMENT OF PUMP PARTS	EXCESSIVE LEAKAGE OR LOSS OF FC-1/FC-2 SUBSYSTEM DUE TO PUMP FAILURE	NOTED VISUALLY OR PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	381 242 374	III	0.38	0.36	0.50	0.07
		M-02	FLANGE SEALS LEAKAGE,	HIGH TEMP. PERMANENT SET	EXTERNAL LEAKS	LEAKS AT PUMP	NOTED VISUALLY	-----	381	IV		0.20	1.00	0.06
		M-03	BROKEN FLANGE SCREW	OVERSTRESS ON MATING FLANGE	ADDED STRESS ON OTHER SCREWS; LEAKS	POSSIBLE LEAK AT PUMP	NOTED VISUALLY	-----	381	IV		0.43	0.50	0.08
SHAFT SEAL ASSEMBLY	SEALS AT DRIVE SHAFT	N-01	SHAFT SEAL TOROIDAL SPRING BREAKS	CORROSION	EVENTUAL LEAKAGE UNDER GROMMET	CONTRIBUTES TO SHAFT SEAL LEAKAGE AS OTHER SEAL ASSY. PARTS DETERIORATE/FAIL	VISUAL	CARBON SEAL; GROMMET	381	IV	87.99	----	1.00	----

LHS FAILURE MODE AND EFFECT ANALYSIS

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SHAFT SEAL ASSEMBLY (CONTINUED)	SEALS AT DRIVE SHAFT	N-02	SHAFT SEAL GROMMET LEAKS	AGE & CHEMICAL CHANGE IN MATERIAL	EVENTUAL LEAKAGE AT SHAFT SEAL ASSEMBLY	SHAFT SEAL LEAKAGE	VISUAL	CARBON SEAL; FLUID REPLENISHMENT AT RESERVOIR	381	IV		0.18	0.90	14.25
		N-03	LOSS OF TENSION OF SHAFT SEAL WAVE SPRING	FATIGUE	SHAFT SEAL LEAKAGE WHEN NOT OPERATING	SHAFT SEAL LEAKAGE	VISUAL	FLUID REPLENISHMENT AT RESERVOIR	381	IV		0.16	0.90	12.67
		N-04	SHAFT SEAL RETAINER BROKEN OR BENT	FAILURE OF SEALING RING	ROTATION OF SEALING ELEMENT ENDED, LEAKAGE INITIATED	SHAFT SEAL LEAKAGE; POSSIBLE LOSS OF FLUID AND SUBSYSTEM FUNCTIONS	VISUAL	FLUID REPLENISHMENT AT RESERVOIR	381	IV		0.02	0.90	1.56
		N-05	CARBON SHAFT SEAL LEAKS	GRADUAL BUILD UP OF SOLID MATERIAL ON SEALING SURFACE	SHAFT SEAL LEAKAGE	POSSIBLE LOSS OF FLUID AND SUBSYSTEM FUNCTIONS	VISUAL	-----	381	IV		0.65	0.05	2.86
		N-06	LEAKING SEAL BETWEEN MATING FLANGE AND MOUNTING RING	DIFFERENTIAL PRESSURE CAUSES WEAR	JOINT LEAKS	PUMP LEAKS	VISUAL	-----	381	IV		0.02	0.50	0.88
TRANSFER PLATE	TRANSFER FLUID FROM CYLINDER TO VALVE BLOCK	O-01	INTERNAL LEAKAGE	WEAR BETWEEN VALVE BLOCK AND TRANSFER PLATE	DECREASE IN PUMP EFFICIENCY	DEGRADATION IN FULL RATE CAPABILITIES OF SYSTEM	REDUCED RESPONSE; COCKPIT PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	242 374	III	5.46	1.00	1.00	5.46
TRANSFER TUBE (5)	TRANSFERS FLUID TO AND FROM CYLINDER BLOCK CYLINDERS	R-01	INTERNAL LEAKAGE-INTERFACES WITH TRANSFER TUBE AND CYLINDER BLOCK	LOW (INTAKE) AND HIGH (OUTPUT) PRESSURE CYCLING CAUSING WEAR	INCREASE IN CASE PRESS., EVENTUAL LOSS OF PUMP EFFICIENCY	GRADUAL DEGRADATION IN FULL RATE CAPABILITIES OF SYSTEM	REDUCED RESPONSE OF SYSTEM COMPONENTS TO FULL RATE REQMTS.	DUAL PISTON RINGS ON EACH END OF TRANSFER TUBE	242 374	III	0.20	1.00	1.00	0.20
WAFER PLATE	PROVIDE HARD SURFACE FOR TRANSFER PLATE ROTATING INTERFACE, &SLOTS/HOLES FOR CONTROL OF FLUID	S-01	EROSION AT INTAKE POINTS	LOW INTAKE PRESSURE SUPPLIED TO PUMP	REDUCED PUMP EFFICENCY	DEGRADATION IN FULL RATE CAPABILITIES OF SYSTEM	REDUCTION IN COMPONENT RATE RESPONSE	FC-1/FC-2 SUBSYSTEM	242 374	III	0.11	1.00	1.00	0.11

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VALVE BLOCK	STRUCTURAL SUPPORT OF WAFER PLATE; PASSAGE FOR PUMP INTAKE AND OUTPUT	W-01	FRACTURE	INTERNAL HYD. STRESS; EXTERNAL STRESSES	LEAKAGE OF FLUID	LOSS OF FC-1/FC-2 SYSTEM CAPABILITY	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 190 381	II	6.98	0.02	0.50	0.07
		W-02	LEAKS AT SEAL - VALVE BLOCK TO HOUSING	DAMAGED	LEAKAGE AT JOINT	EVENTUAL LOSS OF SUBSYSTEM FLUID AND CAPABILITIES	VISIBLE LOSS OF FLUID; PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	381	III		0.01	0.01	----
COMPENSATOR VALVE SUBASSEMBLY	CONTROLS FLOW OF HYDRAULIC FLUID TO YOKE PISTON	X-01	WEAR IN BORE OF COMPENSATOR SLEEVE	MOVEMENT OF VALVE SPOOL IN SLEEVE	LEAKAGE BETWEEN SPOOL & SLEEVE CHANGES PUMP PERFORMANCE CURVE	NO SIGNIFICANT EFFECT; PRESSURE INCORRECT	PRESSURE INDICATOR	COMPENSATOR ADJUSTMENT	525 127	III	68.60	0.12	1.00	8.23
		X-02	SPOOL WEAR	SHARP EDGES WEAR DUE TO FLUID EROSION	CHANGES IN PUMP PERFORMANCE CURVE	NOT SIGNIFICANT; INCORRECT PRESSURE	PRESSURE INDICATOR	COMPENSATOR ADJUSTMENT	525 127	IV		0.28	1.00	19.21
		X-03	LEAKS IN VALVE SLEEVE PACKING	WEAR DUE TO PRESSURE DIFFERENTIAL	CHANGE IN COMPENSATOR FUNCTION	INCORRECT PRESSURE	PRESSURE INDICATOR	COMPENSATOR ADJUSTMENT	525 127	IV		0.004	1.00	0.27
		X-04	LEAK IN VALVE BLOCK TO ADAPTER SEAL	WEAR DUE TO PRESSURE CHANGES	LEAK AT COMPENSATOR	NONE	VISUAL INSPECTION	NONE	381	IV		0.001	1.00	0.07
		X-05	COMPENSATOR SPRING SAG OR BREAK	FATIGUE	CHANGES IN PUMP PERFORMANCE CURVE	INCORRECT PRESSURE	PRESSURE INDICATOR	NONE	525 127	IV		0.60	1.00	41.16
		X-06	LEAK AT PACKING-ADJUSTMENT SCREW TO ADAPTER	WEAR FROM ADJUSTMENT	LEAK AT COMPENSATOR	NONE	VISUAL INSPECTION	NONE	381	IV		----	---	----
		X-07	BROKEN OR LOOSE COMPENSATOR LOCK NUT	FATIGUE; BROKEN LOCK WIRE	CHANGES IN PUMP PERFORMANCE CURVE	INCORRECT PRESSURE	PRESSURE INDICATOR	LOCKWIRE	525 127 070	IV		----	---	----
DISCHARGE ADAPTER	PROVIDES THREADED CONNECTION TO SYSTEM	Y-01	LEAKS IN SEALS-ADAPTER TO VALVE BLOCK	DAMAGED SEAL SURFACES	LEAK AT PUMP	NONE	VISUAL INSPECTION	NONE	381	IV	0.13	1.00	1.00	0.13

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_0
MOUNTING FLANGE	MOUNTS PUMP TO PRIME MOVER	Z-01	CRACKED OR BROKEN	FATIGUE	WEAR/STRESS ON COUPLING SHAFT; POSSIBLE SHEARED SHAFT OR DAMAGED SPLINE	POSSIBLE LOSS OF SUBSYSTEM PRESSURE	VISUAL INSPECTION; PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	381 730	IV	0.68	1.00	1.00	0.68
MOUNTING CLAMP	SECURES PUMP TO MOUNTING FLANGE	Z1-01	LOOSE CLAMP	VIBRATION	PUMP VIBRATION	POSSIBLE PUMP DAMAGE	VISUAL INSPECTION	-----	381 730	IV	0.24	0.90	0.90	0.19
		Z1-02	FAILED CLAMP	FATIGUE; UNDERDESIGN	PUMP CAN DISASSEMBLE FROM PRIME MOVER	LOSS OF SYSTEM PRESSURE	VISUAL INSPECTION	-----	780	III		0.10	1.00	0.02

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					LOCAL EFFECTS	END RESULTS					λ_p	α	β	λ_o
FC-1 POWER SYSTEM	PROVIDE HYD. PWR. TO FC-1 SUBSYS. COMPONENTS	101.000-01	LOSE HYDRAULIC PRESSURE	PUMP FAILURE, SUBSYSTEM LEAK	-----	FUNCTION LOSS OF: SPEEDBRAKE ACT., ROLL AUTOPILOT ACTUATOR, YAW AUTOPILOT ACTUATOR, REDUCED PERFORMANCE: ROLL FEEL ISOL. ACTUATOR, AILERON&SPOILER ACTUATORS, RUDDER AND UHT ACTUATORS	PRESSURE INDICATOR	FC-2 POWER SYSTEM	242 381	II	SEE COMPONENT FAILURE RATES			

LHS FAILURE MODE AND EFFECT ANALYSIS

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RESERVOIR FC-1	STORAGE OF MAKEUP FLUID AND SYSTEM RETURN FLUID. PROVIDE POSITIVE PRESSURE TO PUMP INLET.	01.002-01	HIGH PRESSURE DYNAMIC SEAL FAILURE	CONTAMINATION/ WEAR/ SCORED CYLINDER/ NIBBLING	INTERNAL AND EXTERNAL LEAKAGE	NO EFFECT FROM INTERNAL LEAKS. EXTERNAL LEAKS MAY EVENTUALLY CAUSE LOSS OF FLUID AND FC-1 PRESSURE.	INTERNAL - NONE EXTERNAL - FLUID LEVEL CHECKS & VISUAL INSPECTIONS	FC-2 SUBSYSTEM	381 935 020 185	II	251.5	0.30	0.10	7.55
		01.002-02	PISTON SEAL FAILURE	CONTAMINATION/ WEAR/ SCORED CYLINDER/ NIBBLING	EXTERNAL LEAKAGE	EVENTUAL LOSS OF SYSTEM FLUID AND LOSS OF FC-1 PRESSURE.	VISUAL INSPECTIONS	FC-2 SUBSYSTEM	381 935 020 185	II		0.30	0.10	7.55
		01.002-03	BINDING/JAMMED PISTON	DENTED CASE	LOSS OF PRESSURE TO PUMP INTAKE-PUMP CAVITATION	POSSIBLE LOSS OF FC-1 SUBSYSTEM PRESSURE.	PRESSURE IND./ MAINTENANCE CHECKS	FC-2 SUBSYSTEM	135 780	II		0.10	0.10	2.52
		01.002-04	CRACKED HOUSING/ FITTINGS	FATIGUE OR DAMAGE	EXTERNAL LEAKAGE	LOSS OF FLUID AND FC-1 SUBSYSTEM	PRESSURE IND./ VISUAL INSPECTIONS	FC-2 SUBSYSTEM	190 381	II		0.30	0.10	7.55
RELIEF VALVE - RESERVOIR FC-1	PROVIDE OVER PRESSURE PROTECTION FOR SYSTEM RESERVOIR; DUMPS FLUID TO OVERBOARD DRAIN.	01.005-01	PREMATURE OPENING OF RELIEF VALVE	WEAK OR DAMAGED SPRING/ DAMAGED POPPET SEAT	PREMATURE DUMP OF FLUID TO OVERBOARD DRAIN.	LOSS OF SYSTEM FLUID AND EVENTUAL LOSS OF SYSTEM PRESSURE. LOW PRESSURE MAY CAUSE PUMP CAVITATION	SYS. FLUID LEVEL INDICATOR AND VISIBLE FLUID FROM OVERBOARD DRAIN	FC-2 SUBSYSTEM	070 684 117 381	II	39.6	0.30	0.80	9.50
		01.005-02	VALVE STICKS OPEN	CONTAMINANTS/ INTERNAL DAMAGE	VALVE FAILS TO CLOSE	LOSS OF SYSTEM FLUID TO OVERBOARD DRAIN, EVENTUAL LOSS OF FC-1 SUBSYSTEM	SYS. FLUID LEVEL INDICATOR AND VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	135 165 170 381	II		0.30	0.80	9.50
		01.005.03	VALVE STICKS CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	HIGH RETURN FLOW/ PRESSURE CAN CAUSE BURSTING/DAMAGE TO RESERVOIR	NONE	FC-2 SUBSYSTEM	135 185 170 381	II		0.10	0.80	3.17
		01.005-04	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.30	0.10	1.19

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
PRESSURE FILTER FC-1	REMOVE CONTAMINANTS FROM SYSTEM FLUID	01.006-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT	EXCESSIVE PRESSURE DROP	NONE	FC-2 SUBSYSTEM	135 185 306	III	630.5	0.10	0.30	18.92
		01.006-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/DAILY	-----	242	IV		0.10	0.30	18.92
		01.006-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	50.44
RETURN FILTER FC-1	REMOVE CONTAMINANTS FROM SYSTEM FLUID	01.007-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT; UNFILTERED OPERATION	EXCESSIVE PRESSURE DROP	NONE	FC-2 SUBSYSTEM	135 185 306	III	359.7	0.10	0.30	10.79
		01.007-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/DAILY	-----	242	IV		0.10	0.30	10.79
		01.007-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	28.78
CASE DRAIN FILTER FC-1	REMOVE CONTAMINANTS FROM SYSTEM FLUID	01.008-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT; UNFILTERED OPERATION	EXCESSIVE PRESSURE DROP	NONE	FC-2 SUBSYSTEM	135 185 306	III	359.7	0.10	0.30	10.79
		01.008-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/DAILY	-----	242	IV		0.10	0.30	10.79
		01.008-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	28.78
PRESSURE SNUBBER FC-1	PROTECTS TRANSDUCER FROM PRESSURE SURGES AND FLUCTUATIONS	01.010-01	CLOGGED FILTER SCREEN/ORIFICE	CONTAMINANTS/ DIRT	SNUBBER DOES NOT FUNCTION PROPERTLY	LOSS OF PRESSURE OR FAULTY INDICATION AT THE PRESSURE INDICATOR	PRESSURE INDICATOR	MAINTENANCE CHECKS	372 185	IV	5.7	0.20	0.30	0.34
		01.010-02	CRACKED HOUSING/ FITTINGS/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.46

LHS FAILURE MODE AND EFFECT ANALYSIS

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PRESSURE TRANSMITTER AND SWITCH FC-1	SENSES SYSTEM PRESSURE	01.011-01	INTERNAL DAMAGE	OVERPRESSURE/ FATIGUE	ERRONEOUS OR NO OUTPUT FROM TRANSMITTER TO INDICATOR	ERRONEOUS OR NO INDICATION OF SYSTEM PRESSURE	FULL FC-1 CONTROL POWER BUT ERRONEOUS OR NO INDICATION OF SYSTEM PRESSURE	MAINTENANCE CHECKS	242	III	295.7	0.80	0.80	189.25
		01.011.02	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.20	0.10	5.91
BLEED VALVE FC-1	BLEEDS AIR FROM SYSTEM (MANUALLY)	01.012.01	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/DIRT	VALVE FAILS TO OPEN	CANNOT BLEED AIR FROM SYSTEM	VISUAL	MAINTENANCE CHECKS	170 185 306	III	6.7	0.10	0.70	0.47
		01.012-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	AIR/FLUID WILL NOT FLOW THROUGH VALVE	CANNOT BLEED AIR FROM SYSTEM	VISUAL	MAINTENANCE CHECKS	180 185 306	III		0.10	0.50	0.34
		01.012-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
QUICK DISCONNECT-PRESSURE (GROUND TEST) FC-1	GROUND TEST PWR. SUPPLY CONNECTION	01.016-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381 020	II	97.6	1.00	0.10	9.76
QUICK DISCONNECT-SUCTION (GROUND TEST) FC-1	GROUND TEST SUCTION CONNECTION	01.017-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381 020	II	67.9	1.00	0.10	6.79
QUICK DISCONNECT-PUMP PRESSURE FC-1	CONNECTS PRESSURE LINE TO PUMP	01.018-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50
QUICK DISCONNECT-PUMP SUCTION FC-1	CONNECTS SUCTION LINE TO PUMP	01.019-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50
QUICK DISCONNECT-PUMP CASE DRAIN FC-1	PROVIDES CONNECTION TO PUMP CASE DRAIN	01.020.01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50

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CHECK VALVE- RUN AROUND FC-1	PROVIDES RETURN FLOW PATH WHEN SYSTEM IS SHUT DOWN	01.048-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	LOSS OF HIGH PRESSURE	SYSTEM PRESSURE CHECKS, PRESSURE INDICATOR	FC-2 SUBSYSTEM	135 306	II	6.7	0.10	0.40	0.27
		01.048-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	FLUID CANNOT FLOW THROUGH VALVE	MAY CAVITATE ACTUATORS	NONE	FC-2 SUBSYSTEM	180 306	II		0.10	0.10	0.07
		01.048-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - FILTER RUN AROUND FC-1	PROVIDES MAKEUP FLUID DURING ONE SYSTEM OPERATION	01.049-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	FLUID CAN BYPASS FILTER	UNFILTERED/ CONTAMINATED FLUID	-----	NORMAL FILTRATION	135 306	III	6.7	0.10	0.60	0.40
		01.049-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	MAKEUP FLUID CANNOT FLOW THROUGH VALVE	SPONGY ACTUATOR RESPONSE	-----	NORMAL FILTRATION	185 306	III		0.10	0.70	0.47
		01.049-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - RETURN FILTER FC-1	PREVENTS BACK FLOW THROUGH FILTER	01.051-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	FLUID ALLOWED TO BACK FLOW THROUGH FILTER	ERRATIC ACTION CAUSED BY DIRT BEING BACKED FLUSHED INTO SYSTEM	NONE	-----	135 306	III	6.7	0.10	0.70	0.47
		01.051-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	SYSTEM FLUID CANNOT FLOW THROUGH FILTER TO RESERVOIR	EXCESSIVE RETURN PRESSURE/ POSSIBLE PUMP DAMAGE	PRESSURE INDICATOR	-----	185 306	II		0.10	0.60	0.40
		01.051-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - PUMP PRESSURE FC-1	PREVENTS PUMP FROM MOTORING WHEN PUMP IS SHUT DOWN	01.052-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	PUMP ROTATION WILL REVERSE UPON SHUT DOWN/POSSIBLE PUMP DAMAGE	AUDIBLE CHECKS	FC-2 SUBSYSTEM	135 306	III	6.7	0.10	0.70	0.47
		01.052-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	FLUID CANNOT FLOW THROUGH VALVE	CANNOT PRESSURIZE SYSTEM/ POSSIBLE PUMP DAMAGE	PRESSURE INDICATOR	FC-2 SUBSYSTEM	185 306	II		0.10	0.60	0.40

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					LOCAL EFFECTS	END RESULTS					λ_p	α	β	λ_o
CHECK VALVE - PUMP PRESSURE (CONTINUED) FC-1	PREVENTS PUMP FROM MOTORING WHEN PUMP IS SHUT DOWN	01.052-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - SYSTEM FILL FC-1	PERMITS SYSTEM FILL; PREVENTS REVERSE FLOW IN FILL LINE	01.053-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	135 306	II	6.7	0.10	0.60	0.40
		01.053-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	FILL FLUID CANNOT FLOW THROUGH VALVE	UNABLE TO FILL SYSTEM	MAINTENANCE CHECKS	FC-2 SUBSYSTEM	185 306	III		0.10	0.70	0.47
		01.053-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
PRESSURE MANIFOLD FC-1	PROVIDES MULTIPLE ACCESS PORTS FOR SUPPLY PRESSURE	01.064-01	CRACKED MANIFOLD/ PORT CONNECTIONS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM PRESSURE & FLUID	PRESSURE INDICATOR/VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II	1.0	1.00	0.10	0.10
RETURN MANIFOLD FC-1	PROVIDES MULTIPLE ACCESS PORTS FOR RETURN FLOW	01.065-01	CRACKED MANIFOLD/ PORT CONNECTIONS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR/VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II	1.0	1.00	0.10	0.10
HOSE - PUMP PRESSURE FC-1	TRANSFERS HIGH PRESSURE FLUID TO SYSTEM	01.067-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-2 SUBSYSTEM	070 381	II	56.6	0.10	1.00	5.66
		01.067-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	3.40
		01.067-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	13.58
HOSE - PUMP SUCTION FC-1	TRANSFERS FLUID FROM RESERVOIR TO PUMP	01.069-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-2 SUBSYSTEM	070 381	II	39.6	0.10	1.00	3.96
		01.069-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION/	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	NONE	FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	2.38
		01.069-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	9.51
HOSE - PUMP CASE DRAIN FC-1	PROVIDES RETURN PATH FOR PUMP INTERNAL LEAKAGE	01.071-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-2 SUBSYSTEM	070 381	II	42.4	0.10	1.00	4.24
		01.071-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION/	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-2 SUBSYSTEM	190 690	II		0.60	0.10	2.55

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HOSE - PUMP CASE DRAIN (CONTINUED) FC-1	PROVIDES RETURN PATH FOR PUMP INTERNAL LEAKAGE	01.071-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	10.19
CHECK VALVE - CASE DRAIN FC-1	PREVENTS FLUID BACK FLOW TO PUMP CASE	01.075-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	POSSIBLE EXCESSIVE CASE PRESSURE	NONE	FC-2 SUBSYSTEM	135 306	III	6.7	0.10	0.50	0.34
		01.075-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ DIRT	VALVE FAILS TO OPEN	CASE PRESSURE BUILDUP/POSSIBLE PUMP DAMAGE	NONE	FC-2 SUBSYSTEM	185 306 170	III		0.10	0.50	0.34
		01.075-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
MANIFOLD - SUCTION DISCONNECT C-1	INTERFACE PUMP SUCTION LINE TO GROUND TEST SUCTION DISCONNECT	01.076-01	CRACKED MANIFOLD AND/OR FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-2 SUBSYSTEM	190 690 381	II	1.0	1.00	0.10	0.10

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FC-2 POWER SYSTEM	PROVIDE HYD. PWR. TO FC-2 SUBSYM. COMPONENTS	02.000-01	LOSE HYDRAULIC PRESSURE	PUMP FAILURE/ SUBSYSTEM LEAK	-----	FUNCTION LOSS OF: LEADING EDGE FLAP ACTUATOR, PITCH AUTOPILOT ACTUATOR, REDUCED PERFORMANCE: ROLL FEEL ISOL. ACTUATOR, AILERON&SPOILER ACTUATORS, RUDDER AND UHT ACTUATORS	PRESSURE INDICATOR	FC-1 POWER SYSTEM; EMERGENCY POWER SYSTEM (IF PUMP FAILS)	242 381	II	SEE COMPONENT FAILURE RATES			

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RESERVOIR FC-2	STORAGE OF MAKEUP FLUID AND SYSTEM RETURN FLUID. PROVIDE POSITIVE PRESSURE TO PUMP INLET.	02.002-01	HIGH PRESSURE DYNAMIC SEAL FAILURE	CONTAMINATION/ WEAR/ SCORED CYLINDER/ NIBBLING	INTERNAL AND EXTERNAL LEAKAGE	NO EFFECT FROM INTERNAL LEAKS. EXTERNAL LEAKS MAY EVENTUALLY CAUSE LOSS OF FLUID AND FC-2 PRESSURE.	INTERNAL - NONE EXTERNAL - FLUID LEVEL CHECKS & VISUAL INSPECTIONS	FC-1 SUBSYSTEM	381 935 020 185	II	251.5	0.30	0.10	7.55
		02.002-02	PISTON SEAL FAILURE	CONTAMINATION/ WEAR/ SCORED CYLINDER/ NIBBLING	EXTERNAL LEAKAGE	EVENTUAL LOSS OF SYSTEM FLUID AND LOSS OF FC-2 PRESSURE.	VISUAL INSPECTIONS	FC-1 SUBSYSTEM	381 935 020 185	II		0.30	0.10	7.55
		02.002-03	BINDING/JAMMED PISTON	DENTED CASE	LOSS OF PRESSURE TO PUMP INTAKE- PUMP CAVITATION	POSSIBLE LOSS OF FC-2 SUBSYSTEM PRESSURE.	PRESSURE IND./ MAINTENANCE CHECKS	FC-1 SUBSYSTEM	135 780	II		0.10	0.10	2.52
		02.002-04	CRACKED HOUSING/ FITTINGS	FATIGUE OR DAMAGE	EXTERNAL LEAKAGE	LOSS OF FLUID AND FC-2 SUBSYSTEM	PRESSURE IND./ VISUAL INSPECTIONS	FC-1 SUBSYSTEM	190 381	II		0.30	0.10	7.55
RELIEF VALVE - SYSTEM PRESSURE FC-2	PROVIDE OVER PRESSURE PROTECTION FOR PRESSURE SYSTEM	02.004-01	PREMATURE OPENING/ LEAKING	WEAK OR DAMAGED SPRING/ DAMAGED POPPET SEAT/ MISADJUSTMENT	PREMATURE DUMP OF FLUID TO RETURN LINE	POWER LOSS/ HYDRAULIC FLUID OVERHEATING	NONE	FC-1 SUBSYSTEM	070 684 117 381	II	101.8	0.10	0.50	5.09
		02.004-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	IF PUMP MALFUNCTIONS, EXCESSIVE PRESSURE BUILDUP CAN CAUSE SYSTEM DAMAGE	NONE	-----	135 185 170 381	II		0.10	0.60	6.11
		02.004-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	8.14

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RELIEF VALVE - RESERVOIR FC-2	PROVIDE OVER PRESSURE PROTECTION FOR SYSTEM RESERVOIR; DUMPS FLUID TO OVERBOARD DRAIN.	02.005-01	PREMATURE OPENING/ LEAKING	WEAK OR DAMAGED SPRING/ DAMAGED POPPET SEAT/ MISADJUSTMENT	PREMATURE DUMP OF FLUID TO OVERBOARD DRAIN.	LOSS OF SYSTEM FLUID AND EVENTUAL LOSS OF SYSTEM PRESSURE. LOW PRESSURE MAY CAUSE PUMP CAVITATION	SYS. FLUID LEVEL INDICATOR AND VISIBLE FLUID FROM OVERBOARD DRAIN	FC-1 SUBSYSTEM	070 664 117 381	II	39.6	0.30	0.80	9.50
		02.005-02	VALVE STUCK OPEN	CONTAMINANTS/ INTERNAL DAMAGE	VALVE FAILS TO CLOSE	LOSS OF SYSTEM FLUID TO OVERBOARD DRAIN, EVENTUAL LOSS OF FC-2 SUBSYSTEM	SYS. FLUID LEVEL INDICATOR AND VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	135 185 170 381	II		0.30	0.80	9.50
		02.005.03	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	HIGH RETURN PRESSURE CAN CAUSE BURSTING/DAMAGE TO RESERVOIR	NONE	-----	135 185 170	II		0.10	0.80	3.17
		02.005-04	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.30	0.10	1.19
PRESSURE FILTER FC-2	REMOVE CONTAMINANTS FROM SYSTEM FLUID	02.006-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT	EXCESSIVE PRESSURE DROP	NONE	FC-1 SUBSYSTEM	135 [illegible] 306	III	630.5	0.10	0.30	18.92
		02.006-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/ DAILY	-----	242	IV		0.10	0.30	18.92
		02.006-03	CRACKED HOUSING/ FITTINGS; SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	50.44
RETURN FILTER FC-2	REMOVE CONTAMINANTS FROM SYSTEM FLUID	02.007-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT	UNFILTERED OPERATION	NONE	FC-1 SUBSYSTEM	135 185 306	III	359.7	0.10	0.30	10.79
		02.007-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/ DAILY	-----	242	IV		0.10	0.30	10.79

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RETURN FILTER FC-2 (CONTINUED)	CONTAMINANTS FROM SYSTEM FLUID	02.007-03	CRACKED HOUSING/ FITTINGS; SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	28.78
CASE DRAIN FILTER FC-2	REMOVE CONTAMINANTS FROM SYSTEM FLUID	02.008-01	FILTER CLOGGED; INDICATOR FAILS TO ACTUATE	BINDING BUTTON ASSEMBLY DUE TO DIRT/CONTAMINANTS	FAILS TO INDICATE CLOGGED ELEMENT	UNFILTERED OPERATION	NONE	FC-1 SUBSYSTEM	135 185 306	III	359.7	0.10	0.30	10.79
		02.008-02	FALSE ACTUATION OF INDICATOR	PRESSURE SURGE	FALSE INDICATION OF CLOGGED ELEMENT	PREMATURE ELEMENT REPLACEMENT	MAINTENANCE CHECKS-PREFLIGHT/ DAILY	-----	242	IV		0.10	0.30	10.79
		02.008-03	CRACKED HOUSING/ FITTINGS; SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	28.78
PRESSURE SNUBBER FC-2	PROTECTS TRANSDUCER FROM PRESSURE SURGES AND PUMP PULSATIONS	02.010-01	CLOGGED FILTER SCREEN/ORIFICE	CONTAMINANTS/ DIRT	SNUBBER DOES NOT FUNCTION PROPERLY	FAULTY INDICATION AT THE PRESSURE INDICATOR	PRESSURE INDICATOR	MAINTENANCE CHECKS	372 185	IV	5.7	0.20	0.30	0.34
		02.010-02	CRACKED HOUSING/ FITTINGS; SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.46
PRESSURE TRANSMITTER AND SWITCH FC-2	SENSES SYSTEM PRESSURE	02.011-01	INTERNAL DAMAGE	OVERPRESSURE/ FATIGUE	ERRONEOUS OR NO OUTPUT FROM TRANSMITTER TO INDICATOR	ERRONEOUS OR NO INDICATION OF SYSTEM PRESSURE	FULL FC-2 CONTROL POWER BUT ERRONEOUS OR NO INDICATION OF SYSTEM PRESSURE	MAINTENANCE CHECKS	242	III	295.7	0.80	0.80	189.25
		02.011.02	CRACKED HOUSING/ FITTINGS	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.20	0.10	5.91
BLEED VALVE FC-2	BLEEDS AIR FROM SYSTEM (MANUALLY)	02.012.01	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/DIRT	VALVE FAILS TO OPEN	CANNOT BLEED AIR FROM SYSTEM	VISUAL	MAINTENANCE CHECKS	170 185 306	III	6.7	0.10	0.70	0.47
		02.012-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	AIR/FLUID WILL NOT FLOW THROUGH VALVE	CANNOT BLEED AIR FROM SYSTEM	VISUAL	MAINTENANCE CHECKS	180 185 306	III		0.10	0.50	0.34
		02.012-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54

LH9 FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
ACCUMULATOR FC-2	PROVIDE BOOTSTRAP PRESSURE FOR EMERGENCY POWER PACKAGE IN THE EVENT FC-2 PUMP FAILS AND RAT IS USED	02.013-01	WILL NOT HOLD CHARGE	CRACKED HOUSING/ BAD PISTON SEAL	NO BOOTSTRAP PRESSURE FOR EMERGENCY POWER PACKAGE	LOSS OF EMERGENCY CAPABILITY	PRESSURE GAGE	-----	135 185 170	II	83.3	0.20	1.00	16.67
		02.013-02	CRACKED HOUSING/ FITTINGS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	6.67
PRESSURE GAGE FC-2	PROVIDES VISUAL INDICATION OF ACCUMULATOR PRESSURE CHARGE	02.014-01	BROKEN/ERRATIC READINGS	OVER PRESSURE/ WEAR/ VIBRATION	INDICATOR ERROR	ACCUMULATOR CHARGE PRESSURE CANNOT BE DETERMINED	ERRATIC READINGS OR NO PRESSURE INDICATION	MAINTENANCE CHECKS	020	III	37.1	1.00	0.80	29.68
SOLENOID SHUTOFF VALVE - PRESSURE DUMP FC-2	TO DUMP ACCUMULATOR BOOTSTRAP PRESSURE	02.015-01	VALVE STUCK OPEN	CONTAMINANTS/ INTERNAL DAMAGE/ SOLENOID BURNOUT	VALVE FAILS TO CLOSE	LOSS OF FC-2 POWER & EMERGENCY SYSTEMS	MAINTENANCE CHECKS	-----	135 185 170	II	14.2	0.10	0.20	0.28
		02.015-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN UPON DEMAND	NONE	FLUID NOT DUMPED WHEN SIGNALED	MAINTENANCE CHECKS	135 185 170	IV		0.05	0.00	0.00
		02.015-03	VALVE CLOGGED	CONTAMINANTS/ DIRT	CANNOT DUMP ACCUMULATOR BOOTSTRAP PRESSURE	NONE	UNABLE TO DUMP ACCUMULATOR PRESSURE	-----	180 306	IV		0.05	0.00	0.00
		02.015-04	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	1.13
QUICK DISCONNECT- PRESSURE (GROUND TEST) FC-2	GROUND TEST PWR. SUPPLY CONNECTION	02.016-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381 020	II	97.6	1.00	0.10	9.76
QUICK DISCONNECT- SUCTION (GROUND TEST) FC-2	GROUND TEST SUCTION CONNECTION	02.017-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381 020	II	67.9	1.00	0.10	6.79
QUICK DISCONNECT- PUMP PRESSURE FC-2	CONNECTS PRESSURE LINE TO PUMP	02.018-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50

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QUICK DISCONNECT- PUMP SUCTION FC-2	CONNECTS SUCTION LINE TO PUMP	02.019-01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50
QUICK DISCONNECT- PUMP CASE DRAIN FC-2	PROVIDES CONNECTION TO PUMP CASE DRAIN	02.020.01	MALFUNCTION	INTERNAL WEAR/ FATIGUE/CRACKED/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381 020	II	365.0	1.00	0.10	36.50
CHARGE VALVE - ACCUMULATOR FC-2	PROVIDE INPUT PORT FOR CHARGING ACCUMULATOR	02.027-01	VALVE STUCK OPEN	CONTAMINANTS/ INTERNAL DAMAGE	VALVE FAILS TO CLOSE	CANNOT MAINTAIN ACCUMULATOR CHARGE	PRESSURE GAGE/ MAINTENANCE CHECKS	-----	135 185 170	III	6.9	0.10	0.70	0.48
		02.027-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	CANNOT CHARGE ACCUMULATOR	MAINTENANCE CHECKS	-----	135 185 170	III		0.10	0.60	0.42
		02.027-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	CANNOT CHARGE ACCUMULATOR	MAINTENANCE CHECKS	FC-1 SUBSYSTEM	190 690 381	III		0.80	0.10	0.55
CHECK VALVE- RUN AROUND FC-2	PROVIDES RETURN FLOW PATH WHEN SYSTEM IS SHUT DOWN	02.048-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSED	LOSS OF HIGH PRESSURE	SYSTEM PRESSURE CHECKS, PRESSURE INDICATOR	FC-1 SUBSYSTEM	135 306	II	6.7	0.10	0.40	0.27
		02.048-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	FLUID CANNOT FLOW THROUGH VALVE	MAY CAVITATE ACTUATORS	NONE	FC-1 SUBSYSTEM	180 306	II		0.10	0.10	0.07
		02.048-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - FILTER RUN AROUND FC-2	PROVIDES MAKEUP FLUID DURING ONE SYSTEM OPERATION	02.049-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	FLUID CAN BYPASS FILTER	UNFILTERED/ CONTAMINATED FLUID	NONE	NORMAL FILTRATION	135 306	III	6.7	0.10	0.60	0.40
		02.049-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	MAY CAVITATE ACTUATORS	SPONGY ACTUATOR RESPONSE	-----	NORMAL FILTRATION	185 306	III		0.10	0.70	0.47
		02.049-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54

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CHECK VALVE - ACCUMULATOR ISOLATOR FC-2	PROVIDES TRAPPED BOOTSTRAP PRESSURE FOR EMERGENCY OPERATION	01.049A-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	LOSE BOOTSTRAP PRESSURE WHEN PUMP IS SHUT DOWN OR LOST	LOSS OF EMERGENCY OPERATION CAPABILITY	SYSTEM RESPONSE CHECKS	FC-1 SUBSYSTEM	135 306	II	6.7	0.20	0.60	0.81
		02.049A-02	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - RETURN FILTER FC-2	PREVENTS BACK FLOW THROUGH FILTER	02.051-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	FLUID ALLOWED TO BACK FLOW THROUGH FILTER	ERRATIC ACTION CAUSED BY DIRT BEING BACK FLUSHED INTO SYSTEM	NONE	-----	135 306	III	6.7	0.10	0.70	0.47
		02.051-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	SYSTEM FLUID CANNOT FLOW THROUGH FILTER TO RESERVOIR	EXCESSIVE RETURN PRESSURE AND POSSIBLE PUMP DAMAGE	NONE	-----	185 306	III		0.10	0.60	0.40
		02.051-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - RAT REGULATED OUTPUT FC-2	PORTS EMERGENCY SYSTEM FLOW INTO FC-2 SYSTEM	02.051A-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	FLUID ALLOWED TO BACK FLOW THROUGH PRESSURE REGULATOR	OVER PRESSURIZE RETURN SYSTEM/ POSSIBLE PUMP DAMAGE	SYSTEM CHECKS	NONE	135 306	III	6.7	0.10	0.60	0.40
		02.051A-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	PREVENTS EMERGENCY FLUID FLOW	LOSS OF EMERGENCY OPERATION CAPABILITY	SYSTEM CHECKS	NONE	185 306	III		0.10	0.70	0.47
		02.051A-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - PUMP PRESSURE FC-2	PREVENTS PUMP FROM MOTORING WHEN PUMP IS IS SHUT DOWN	02.052-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	PUMP ROTATION WILL REVERSE UPON SHUT DOWN/POSSIBLE PUMP DAMAGE	AUDIBLE CHECKS	FC-1 SUBSYSTEM	135 306	III	6.7	0.10	0.70	0.47
		02.052-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	FLUID CANNOT FLOW THROUGH VALVE	CANNOT PRESSURIZE SYSTEM/ POSSIBLE PUMP DAMAGE	PRESSURE INDICATOR	FC-1 SUBSYSTEM	185 306	III		0.10	0.60	0.40

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CHECK VALVE - PUMP PRESSURE FC-2 (CONTINUED)	PREVENTS PUMP FROM MOTORING WHEN PUMP IS IS SHUT DOWN	02.052-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - SYSTEM FILL FC-2	PERMITS SYSTEM FILL; PREVENTS REVERSE FLOW IN FILL LINE	02.053-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	135 306	II	6.7	0.10	0.60	0.40
		02.053-02	VALVE STUCK CLOSED	CONTAMINANTS/ DIRT	FILL FLUID CANNOT FLOW THROUGH VALVE	UNABLE TO FILL SYSTEM	MAINTENANCE CHECKS	FC-1 SUBSYSTEM	185 306	III		0.10	0.70	0.47
		02.053-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - CASE DRAIN FC-2	PREVENTS FLUID BACK FLOW TO PUMP CASE	02.055-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	POSSIBLE EXCESSIVE CASE PRESSURE	NONE	FC-1 SUBSYSTEM	135 306	III	6.7	0.10	0.50	0.34
		02.055-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ DIRT	VALVE FAILS TO OPEN	CASE PRESSURE BUILDUP/POSSIBLE PUMP DAMAGE	NONE	FC-1 SUBSYSTEM	185 306 170	III		0.10	0.50	0.30
		02.055-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
CHECK VALVE - RAT BYPASS RETURN FC-2	PROVIDES MAKEUP FLUID DURING ONE SYSTEM OPERATION	02.056-01	VALVE STUCK CLOSED	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO OPEN	MAKEUP FLUID CANNOT FLOW THROUGH VALVE WHEN PUMP IS SHUT DOWN OR LOST	SPONGY RESPONSE	-----	135 306	II	6.7	0.10	0.70	0.47
		02.056-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	MAKEUP FLUID CANNOT FLOW THROUGH VALVE	MAKEUP FLUID CANNOT FLOW THROUGH VALVE WHEN PUMP IS SHUT DOWN OR LOST	SPONGY RESPONSE	-----	185 306	II		0.10	0.60	0.40
		02.056-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54

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HOSE - PUMP PRESSURE FC-2	TRANSFERS HIGH PRESSURE FLUID TO SYSTEM	02.068-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	070 381	II	73.6	0.10	1.00	7.36
		02.068-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION/	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.60	0.10	4.41
		02.068-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	17.65
HOSE - PUMP SUCTION FC-2	TRANSFERS FLUID FROM RESERVOIR TO PUMP	02.070-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	070 381	II	110.3	0.10	1.00	11.03
		02.070-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION/	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	190 690 381	II		0.60	0.10	6.62
		02.070-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	26.47
HOSE - PUMP CASE DRAIN FC-2	PROVIDES RETURN PATH FOR PUMP INTERNAL LEAKAGE	02.072-01	RUPTURED HOSE	FATIGUE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	070 381	II	73.6	0.10	1.00	7.36
		02.072-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION/	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1 SUBSYSTEM	190 690	II		0.60	0.10	4.41
		02.072-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	-----	020 690	IV		0.30	0.80	17.65
CHECK VALVE - RAT FC-2	PREVENTS REVERSE FLOW DURING EMERGENCY OPERATION	02.073-01	VALVE STUCK CLOSED	INTERNAL DAMAGE/ DIRT	OVER PRESSURE TO PUMP CASE	POSSIBLE PUMP DAMAGE	NONE	-----	135 306	III	6.7	0.10	0.70	0.47
		02.073-02	VALVE STUCK OPEN	CONTAMINANTS/ DIRT	NONE	LOSS OF EMERGENCY OPERATION CAPABILITY	NONE	-----	185 306	III		0.10	0.60	0.40
		02.073-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
PRESSURE MANIFOLD FC-2	PROVIDES COMMON LOCAL ACCESS POINTS FOR PRESSURE GAGE, FILL VALVE, & ACCUMULATOR CHARGE LINE	02.074-01	CRACKED MANIFOLD/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL SHOCK	LOSS OF ACCUMULATOR CHARGE	LOSS OF EMERGENCY OPERATION CAPABILITY	PRESSURE INDICATOR	FC-1 SUBSYSTEM	190 690 381	II	1.0	1.00	0.10	0.10

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RELIEF VALVE FC-1	PROVIDE OVER PRESSURE PROTECTION FOR PRESSURE SYSTEM AND FOR SPEED BRAKE BLOW BACK & THERMAL RELIEF	03.004-01	PREMATURE OPENING/ LEAKING	WEAK OR DAMAGED SPRING/ DAMAGED POPPET SEAT/ MISADJUSTMENT	PREMATURE DUMP OF FLUID TO RETURN LINE	POWER LOSS/ HYDRAULIC FLUID OVERHEATING	NONE	-----	070 684 117 381	II	101.8	0.16	0.50	5.09
		03.004-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	IF PUMP MALFUNCTIONS EXCESSIVE PRESSURE BUILDUP CAN CAUSE SYSTEM DAMAGE	NONE	-----	135 165 170 381	II		0.10	0.60	6.11
		03.004-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL; FLUID LEVEL INDICATOR	-----	190 690 381	II		0.80	0.10	8.14
SPEED BRAKE SELECTOR VALVE FC-1	PORTS FLUID TO SPEED BRAKE ACTUATOR UPON DIRECTIONAL COMMAND	03.021-01	MALFUNCTIONING/ INOPERATIVE	CONTAMINANTS/ INTERNAL DAMAGE	VALVE FAILS TO FOLLOW COMMAND	LOSS OF SPEED BRAKE CONTROL	NO ACTUATOR RESPONSE; SPEED BRAKE OPERATIONAL CHECKS	-----	135 185 170 381	II	540.2	0.42	0.40	90.75
		03.021-02	VALVE LEAKING	WEAR/FAILED SEAL	POSSIBLE FLUID EROSION	POWER LOSS/ POSSIBLE FLUID OVERHEATING	NONE	-----	180 306	III		0.45	0.40	97.24
		03.021-03	CRACKED HOUSING/ FITTINGS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.13	0.10	7.02
SPEED BRAKE RESTRICTOR - TWO WAY	LIMITS PISTON SPEED BY LIMITING FLOW RATE TO ACTUATOR	03.028-01	RESTRICTOR CLOGGED	CONTAMINANTS/ DIRT	FLUID FLOW RESTRICTION	REDUCED OPERATING SPEED; POSSIBLE LOSS OF SPEED BRAKE	SPEED BRAKE OPERATIONAL CHECKS	-----	180 306	III	34.7	0.29	0.50	5.02
		03.028-02	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.71	0.10	2.46
SPEED BRAKE SWIVEL JOINT - EXTEND	TRANSFER FLUID TO ACTUATOR; ALLOWS MOVEMENT OF ACTUATOR	03.033-01	LEAKAGE	WEAR/DAMAGED SEALS	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II	148.6	0.95	0.10	14.12
SPEED BRAKE SWIVEL JOINT - RETRACT	TRANSFER FLUID TO ACTUATOR; ALLOWS MOVEMENT OF ACTUATOR	03.034-01	LEAKAGE	WEAR/DAMAGED SEALS	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II	148.6	0.95	0.10	14.12

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SPEED BRAKE CHECK VALVE - RETURN	PROVIDES MAKEUP FLUID FOR SPEED BRAKE ACTUATOR RETRACTION DURING BLOWBACK	03.044-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	LOSS OF SYSTEM/ SPEED BRAKE CONTROL	SPEED BRAKE OPERATIONAL CHECKS	-----	135 306	II	6.7	0.10	0.50	0.34
		03.044-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	MAKEUP FLUID WILL NOT BE SUPPLIED	SPEED BRAKE OPERATIONAL CHECKS	-----	135 185 170	II		0.10	0.50	0.34
		03.044-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.80	0.10	0.54
SPEED BRAKE CHECK VALVE - PRESSURE	PROVIDE FOR FLUID THERMAL EXPANSION	03.045-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	FLUID WILL BYPASS SELECTOR VALVE TO ACTUATOR	SPEED BRAKE STUCK IN RETRACT POSITION	-----	135 306	II	6.7	0.10	0.50	0.34
		03.045-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	POSSIBLE DAMAGE DUE TO FLUID THERMAL EXPANSION	NONE	-----	135 185 170	III		0.10	0.50	0.34
		03.045-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.80	0.10	0.54
SPEED BRAKE CHECK VALVE - PRESSURE	PROVIDE FLUID RETURN TO MANIFOLD DURING SPEED BRAKE BLOWBACK	03.047-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	FLUID WILL BYPASS SELECTOR VALVE TO ACTUATOR	SPEED BRAKE STUCK IN EXTEND POSITION	-----	135 306	II	6.7	0.01	0.60	0.04
		03.047-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	FLUID CANNOT RETURN TO MANIFOLD DURING SPEED BRAKE BLOWBACK	NONE	-----	135 185 170	II		0.10	0.70	0.47
		03.047-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.80	0.10	0.54
SPEED BRAKE CHECK VALVE - PRESSURE	PREVENT PRESSURE SURGES FROM ENTERING SYSTEM DURING SPEED BRAKE OPERATION	03.050-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	POSSIBLE PRESSURE SURGES MAY ENTER MAIN SYSTEM	NONE	-----	135 306	III	6.7	0.10	0.50	0.34
		03.050-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	LOSS OF SPEED BRAKE CONTROL	NO ACTUATOR RESPONSE	-----	135 185 170	II		0.10	0.50	0.34

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SPEED BRAKE CHECK VALVE - PRESSURE (CONTINUED)	PREVENT PRESSURE SURGES FROM ENTERING SYSTEM DURING SPEED BRAKE OPERATION	03.050-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.80	0.10	0.54
SPEED BRAKE MANIFOLD	PROVIDES COMMON LOCAL ACCESS FOR SPEED BRAKE SYSTEM PLUMBING	03.066-01	CRACKED MANIFOLD/ PORT CONNECTIONS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II	1.0	1.00	0.10	0.10
SPEED BRAKE ACTUATOR	CONVERTS FLUID ENERGY INTO MECHANICAL MOVEMENT OF SPEED BRAKE	03-107-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 117 185 381	II	127.2	0.40	0.10	5.09
		03-107-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.02	0.50	1.27
		03-107-03	SCORED/PITTED PISTON ROD	WEAR/DIRT/DAMAGE/ CORROSION/ CONTAMINATION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	935 520 170 185	II		0.11	0.10	1.40
		03-107-04	DAMAGED PISTON SEAL/GLAND	FATIGUE/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE	SLOWER EXTEND - FASTER RETRACT IN FLIGHT; SNUBBING REDUCED	SPEED BRAKE PERFORMANCE CHECKS	-----	020 306 381	III		0.15	0.30	5.72
		03-107-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL DAMAGE	POSSIBLE INTERNAL LEAKAGE; CYLINDER BORE SCORING/ BINDING	POSSIBLE ROUGH SPEED BRAKE OPERATION	ACTUATOR PERFORMANCE CHECKS	-----	190 935 760 381	III		0.01	0.30	0.38
		03-107-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ INTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE	NONE	ACTUATOR DISASSEMBLY	-----	520 935 170 185	IV		0.01	0.00	0.00
		03-107-07	CRACKED HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.15	0.10	1.91

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SPEED BRAKE ACTUATOR (CONTINUED)	CONVERTS FLUID ENERGY INTO MECHANICAL MOVEMENT OF SPEED BRAKE	03-107-08	JAMMED LOCK	INTERNAL DAMAGE/ CONTAMINATION	SPEED BRAKE LOCKED IN RETRACT POSITION	NO EXTENSION POSSIBLE	SPEED BRAKE PERFORMANCE CHECKS	-----	135 185	II		0.03	0.80	3.05
		03-107-09	BROKEN LOCKING MECHANIZATION SPRING	FATIGUE/ INTERNAL DAMAGE	NO EFFECT IN FLIGHT	SURFACE DROOPS AFTER SHUT DOWN	ACTUATOR PERFORMANCE CHECKS	-----	070	IV		0.08	0.20	2.04
RFI ACTUATOR COILED TUBING - FC-2 PRESS. BRKT. (2)	PROVIDES FLEXIBLE FLUID CONNECTION TO RFI ACTUATOR	04.057-01	CRACKED TUBING/ LEAKING FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; OPERATIONAL CHECKS	-----	070 190 381	II	106.5	1.00	0.60	63.90
RFI ACTUATOR COILED TUBING - FC-1 PRESS. BRKT. (2)	PROVIDES FLEXIBLE FLUID CONNECTION TO RFI ACTUATOR	04.058-01	CRACKED TUBING/ LEAKING FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; OPERATIONAL CHECKS	-----	070 190 381	II	106.5	1.00	0.60	63.90
ROLL FEEL ISOLATION (RFI) ACTUATOR	PROVIDES FLUID AMPLIFICATION OF PILOT INPUTS; PREVENTS OUTPUT FROM AFCS ROLL ACTUATOR FROM FEEDING BACK TO PILOT'S STICK	04-105-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 117 185 381	II	300.0	0.08	0.10	2.41
		04-105-02	BENT ACTUATOR PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.02	0.60	3.61
		04-105-03	SCORED/PITTED ACTUATOR PISTON ROD	WEAR/DIRT/DAMAGE/ CORROSION/ CONTAMINATION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	935 520 170 185	II		0.08	0.10	2.41
		04-105-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE	NONE	NONE	-----	020 306 381	IV		0.08	0.00	0.00
		04-105-05	CRACKED/SCORED/ DISTORTED ACTUATOR PISTON	INTERNAL/EXTERNAL DAMAGE; FATIGUE	POSSIBLE INTERNAL LEAKAGE	POSSIBLE ROUGH RFI OPERATION	RFI ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	190 935 780 381	III		0.06	0.30	5.41

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ROLL FEEL ISOLATION (RFI) ACTUATOR (CONTINUED)	PROVIDES FLUID AMPLIFICATION OF PILOT INPUTS; PREVENTS OUTPUT FROM AFCS ROLL ACTUATOR FROM FEEDING BACK TO PILOT'S STICK	04-105-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ INTERNAL DAMAGE/ CONTAMINATION	EXCESSIVE PISTON SEAL WEAR	NONE	NONE	DUAL TANDEM CYLINDER	520 935 170 185	IV		0.06	0.00	0.00
		04-105-07	CRACKED ACTUATOR HOUSING/CAP/ CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID; LOSS OF BOTH FC POWER SYSTEMS IF CRACK PROPAGATES ACROSS PARTITION	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	I		0.08	0.10	2.41
		04-105-08	DAMAGED ACTUATOR ARM	FATIGUE/BINDING/ EXTERNAL DAMAGE	SERVO VALVE INOPERATIVE	LOSS OF ROLL CONTROL	ROLL AXIS PERFORMANCE CHECKS	-----	135 780	I		0.05	0.40	6.02
		04-105-09	DAMAGED PRELOAD SPRING ASSEMBLY	FATIGUE/ EXTERNAL DAMAGE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN ACTUATOR PERFORMANCE	RFI ACTUATOR PERFORMANCE CHECKS	-----	135 780	IV		0.04	0.30	3.61
		04-105-10	DAMAGED SPOOL ROD SEAL IN SERVO VALVE	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	020 306 381	II		0.08	0.10	2.41
		04-105-11	BENT SERVO VALVE SPOOL	FATIGUE/ EXTERNAL FORCE	SPOOL BINDING/ STICKING	POOR OR NO RFI ACTUATOR RESPONSE	RFI ACTUATOR PERFORMANCE CHECKS	-----	135 780	II		0.02	0.40	2.41
		04-105-12	SCORED/PITTED SERVO VALVE SPOOL ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	185 520 935 170	II		0.08	0.10	2.41
		04-105-13	WORN/SCORED/SERVO VALVE SPOOL METERING EDGES	CONTAMINATION/ EROSION/CORROSION	INCREASED INTERNAL LEAKAGE	INCREASED POWER LOSS	RFI ACTUATOR PERFORMANCE CHECKS	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	170 185 935 020	III		0.06	0.50	9.02
		04-105-14	CRACKED SERVO VALVE HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.08	0.10	2.41

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ROLL FEEL ISOLATION (RFI) ACTUATOR (CONTINUED)	PROVIDES FLUID AMPLIFICATION OF PILOT INPUTS; PREVENTS OUTPUT FROM AFCS ROLL ACTUATOR FROM FEEDING BACK TO PILOT'S STICK	04-105-15	DAMAGED SERVO VALVE PRELOAD SPRING	FATIGUE/DAMAGED SPRING GUIDE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN ACTUATOR PERFORMANCE	RFI ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	135 780	IV		0.04	0.30	3.61
		04-105-16	SERVO VALVE/ ACTUATOR CONNECTOR DAMAGE/ CRACKING	FATIGUE/ VIBRATION/ CORROSION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381 170	II		0.08	0.10	2.41
AUTOPILOT SYSTEM - SELECTOR VALVE	DIRECTS SYSTEM FLUID TO AUTOPILOT ACTUATORS	05.025-01	MALFUNCTIONING/ INOPERATIVE	CONTAMINANTS/ INTERNAL DAMAGE	VALVE FAILS TO OPEN/CLOSE	LOSS OF AUTOPILOT CONTROL (ROLL/ PITCH/YAW)	OPERATIONAL CHECKS	FC-1/FC-2 SUBSYSTEM	180 170	II	15.1	0.30	0.40	1.81
		05.025-02	CRACKED HOUSING/ FITTINGS; SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; OPERATIONAL CHECKS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.70	0.10	1.06
AFCS ACTUATOR (PITCH, ROLL, YAW) (3)	ACCEPT ELECTRICAL INPUT SIGNALS FOR AUTOMATIC CONTROL OF ROLL, PITCH, & YAW	05-106-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	BACKUP SEALS	020 306 381	II	334.3	0.18	0.10	6.02
		05-106-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.06	0.60	12.03
		05-106-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL PARALLEL CYLINDERS	185 520 935 170	II		0.14	0.10	4.68
		05-106-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE	NONE	ACTUATOR PERFORMANCE CHECKS	DUAL PARALLEL CYLINDERS	020 306 381	IV		0.11	0.00	0.00
		05-106-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE/ BINDING	DEGRADED ACTUATOR PERFORMANCE	ACTUATOR PERFORMANCE CHECKS	DUAL PARALLEL CYLINDERS	190 935 780 381	III		0.08	0.30	8.02

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AFCS ACTUATOR (PITCH, ROLL, YAW) (3) (CONTINUED)	ACCEPT ELECTRICAL INPUT SIGNALS FOR AUTOMATIC CONTROL OF ROLL, PITCH, & YAW	05-106-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ INTERNAL DAMAGE/ CONTAMINATION	EXCESSIVE PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	DUAL PARALLEL CYLINDERS	520 935 170 185	IV		0.13	0.00	0.00
		05-106-07	CRACKED ACTUATOR/ SERVO VALVE HOUSING/CAP/ CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.16	0.10	5.35
		05-106-08	DAMAGED FACE SEALS IN SERVO VALVE	NIBBLING/ DETERIORATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	117 381	II		0.18	0.10	6.02
COILED TUBING - SPOILER ACTUATOR FC-1 PRESS.&RET. (2)	PROVIDES FLEXIBLE FLUID CONNECTION TO SPOILER ACTUATOR	06.060-01	CRACKED TUBING/ LEAKING FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; OPERATIONAL CHECKS	FC-1/FC-2 SUBSYSTEM	070 190 381	II	106.5	1.00	0.60	63.90
COILED TUBING - SPOILER ACTUATOR FC-2 PRESS.&RET. (2)	PROVIDES FLEXIBLE FLUID CONNECTION TO SPOILER ACTUATOR	06.061-01	CRACKED TUBING/ LEAKING FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; OPERATIONAL CHECKS	FC-1/FC-2 SUBSYSTEM	070 190 381	II	106.5	1.00	0.60	63.90
AILERON HOSE - FC-2 PRESSURE	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.077-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.077-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.077-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-2 RETURN	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.078-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.078-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95

LHS FAILURE MODE AND EFFECT ANALYSIS

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AILERON HOSE - FC-2 RETURN (CONTINUED)	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.078-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-1 RETURN	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.079-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.079-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.079-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-1 PRESSURE	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.080-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.080-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.080-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-2 PRESSURE	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.081-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.081-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.081-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-2 RETURN	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.082-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.082-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.082-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79

LHS FAILURE MODE AND EFFECT ANALYSIS

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AILERON HOSE - FC-1 RETURN	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.083-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.083-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.083-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON HOSE - FC-1 PRESSURE	PROVIDES FLEXIBLE FLUID CONNECTION TO AILERON ACTUATOR	06.084-01	RUPTURED HOSE	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	PRESSURE INDICATOR	FC-1/FC-2 SUBSYSTEM	070 381	II	115.8	0.10	1.00	11.58
		06.084-02	CRACKED FITTING/ CONNECTOR	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.60	0.10	6.95
		06.084-03	DEGRADED/ LEAKING HOSE	VIBRATION AND/OR CHAFING	CHAFED HOSE OR WORN SPOTS	COULD RESULT IN HOSE FAILURE	VISUAL INSPECTIONS	FC-1/FC-2 SUBSYSTEM	020 690	IV		0.30	0.80	27.79
AILERON ACTUATOR (2)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF AILERON CONTROL SURFACES	06-101-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 306 381	II	454.2	0.08	0.10	3.63
		06-101-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	IV		0.02	0.60	5.45
		06-101-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	185 520 935 170	II		0.08	0.10	3.63
		06-101-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE	NONE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	020 306 381	IV		0.03	0.00	0.00

LHG FAILURE MODE AND EFFECT ANALYSIS

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AILERON ACTUATOR (2) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF AILERON CONTROL SURFACES	06-101-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE/ BINDING	POSSIBLE ROUGH OPERATION	POOR ACTUATOR RESPONSE	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	190 935 780 381	III		0.03	0.30	4.09
		06-101-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ CONTAMINATION	INCREASED PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	520 935 170 185	IV		0.07	0.00	0.00
		06-101-07	CRACKED ACTUATOR/ SERVO VALVE HOUSING/CAP/ CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID ; LOSS OF BOTH FC SYSTEMS IF CRACK PROPAGATES ACROSS PARTITION	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	I		0.09	0.10	4.09
		06-101-08	DAMAGED ACTUATOR ARM	FATIGUE/BINDING/ EXTERNAL DAMAGE	SERVO VALVE INOPERATIVE	NO AILERON ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	I		0.04	0.40	7.27
		06-101-09	DAMAGED PRELOAD SPRING ASSEMBLY	FATIGUE/ EXTERNAL DAMAGE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN PERFORMANCE	ACTUATOR PERFORM. CHECKS	-----	135 780	IV		0.04	0.30	5.45
		06-101-10	DAMAGED SPOOL ROD SEAL IN SERVO VALVE	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	020 306 381	II		0.08	0.01	0.36
		06-101-11	BENT SERVO VALVE SPOOL ROD	FATIGUE/EXTERNAL FORCE	SPOOL BINDING	POOR OR NO AILERON ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	II		0.02	0.40	3.63
		06-101-12	SCORED/PITTED SERVO VALVE SPOOL ROD	CORROSION/WEAR/ CONTAMINATION	INCREASED ROD SEAL WEAR	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	170 185 935 520	II		0.07	0.10	3.18
		06-101-13	DAMAGED SEALS ON SERVO VALVE SLEEVE	NIBBLING/WEAR/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL/EXTERNAL LEAKAGE	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID/ ACTUATOR DISASSEMBLY	DUAL TANDEM CYLINDER	020 185 381	II		0.08	0.10	3.63
		06-101-14	WORN/SCORED/SERVO VALVE SPOOL METERING EDGES	CONTAMINATION/ EROSION/CORROSION	INCREASED INTERNAL LEAKAGE	INCREASED POWER LOSS	ACTUATOR PERFORM. CHECKS	DUAL TANDEM CYLINDER	170 185 935 020	II		0.04	0.50	9.08

LHS FAILURE MODE AND EFFECT ANALYSIS

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AILERON ACTUATOR (2) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF AILERON CONTROL SURFACES	06-101-15	CRACKED SERVO VALVE HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.07	0.10	3.18
		06-101-16	DAMAGED SERVO VALVE PRELOAD SPRING	FATIGUE/DAMAGED SPRING GUIDE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN ACTUATOR PERFORMANCE	ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	135 780	IV		0.04	0.40	7.27
		06-101-17	SERVO VALVE/ ACTUATOR CONNECTOR DAMAGE/ CRACKING	FATIGUE/ VIBRATION/ CORROSION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381 170	II		0.09	0.10	4.09
SPOILER ACTUATOR (2)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF SPOILER/DEFLECTOR CONTROL SURFACES	06-102-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE SEALS	020 306 381	II	189.1	0.07	0.10	1.32
		06-102-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORM. CHECKS	-----	135 780	III		0.02	0.60	2.27
		06-102-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	185 520 935 170	II		0.09	0.10	1.70
		06-102-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE	REDUCED OR LOSS OF ACTUATOR FORCE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	020 306 381	II		0.03	0.30	1.70
		06-102-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL/ EXTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE/ BINDING	POSSIBLE ROUGH OPERATION	POOR ACTUATOR RESPONSE	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	190 935 780 381	III		0.04	0.30	2.27
		06-102-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ CONTAMINATION	INCREASED PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	520 935 170 185	IV		0.09	0.00	0.00
		06-102-07	CRACKED ACTUATOR/ SERVO VALVE HOUSING/CAP/ CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID & LOSS OF BOTH FC SYSTEMS IF CRACK PROPAGATES ACROSS PARTITION	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	I		0.07	0.10	1.32

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SPOILER ACTUATOR (3) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF SPOILER/DEFLECTOR CONTROL SURFACES	06-102-08	DAMAGED ACTUATOR ARM	FATIGUE/BINDING/ EXTERNAL DAMAGE	SERVO VALVE INOPERATIVE	NO SPOILER ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	I		0.05	0.40	3.78
		06-102-09	DAMAGED PRELOAD SPRING ASSEMBLY	FATIGUE/ EXTERNAL DAMAGE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN PERFORMANCE	ACTUATOR PERFORM. CHECKS	-----	135 780	IV		0.04	0.30	2.27
		06-102-10	DAMAGED SPOOL ROD SEAL IN SERVO VALVE	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	020 306 381	II		0.07	0.10	1.32
		06-102-11	BENT SERVO VALVE SPOOL ROD	FATIGUE/EXTERNAL FORCE	SPOOL BINDING	POOR OR NO SPOILER ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	II		0.02	0.40	1.51
		06-102-12	SCORED/PITTED SERVO VALVE SPOOL ROD	CORROSION/WEAR/ CONTAMINATION	INCREASED ROD SEAL WEAR	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	170 185 935 520	II		0.09	0.10	1.70
		06-102-13	DAMAGED SEALS ON SERVO VALVE SLEEVE	NIBBLING/WEAR/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL/EXTERNAL LEAKAGE	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID/ ACTUATOR DISASSEMBLY	DUAL TANDEM CYLINDER	020 185 381	II		0.07	0.10	1.32
		06-102-14	WORN/SCORED/SERVO VALVE SPOOL METERING EDGES	CONTAMINATION/ EROSION/CORROSION	INCREASED INTERNAL LEAKAGE	INCREASED POWER LOSS	ACTUATOR PERFORM. CHECKS	DUAL TANDEM CYLINDER	170 185 935 020	II		0.06	0.50	5.67
		06-102-15	CRACKED SERVO VALVE HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.07	0.10	1.32
		06-102-16	DAMAGED SERVO VALVE PRELOAD SPRING	FATIGUE/DAMAGED SPRING GUIDE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN ACTUATOR PERFORMANCE	ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	135 780	IV		0.04	0.40	3.03
		06-102-17	SERVO VALVE/ ACTUATOR CONNECTOR DAMAGE/ CRACKING	FATIGUE/ VIBRATION/ CORROSION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381 170	II		0.07	0.10	1.32

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LEADING EDGE FLAP RESTRICTOR - ONE WAY (2)	LIMITS PISTON SPEED DURING EXTENSION	07.030-01	POPPET STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	FLUID RESTRICTION IN BOTH DIRECTIONS	L.E. FLAPS MOVE SLOWLY DURING RETRACTION	OPERATIONAL CHECKS	-----	135 185 170	III	34.7	0.19	0.50	3.30
		07.030-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	FLUID RESTRICTION	POSSIBLE LOSS OF L.E. FLAP CONTROL	OPERATIONAL CHECKS	-----	185 306	II		0.11	0.50	1.91
		07.030-03	CRACKED HOUSING/ PORT;SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; PRESSURE INDICATOR	-----	190 690 381	II		0.70	0.10	2.43
LEADING EDGE FLAP RESTRICTOR - ONE WAY (2)	LIMITS PISTON SPEED DURING EXTENSION	07.031-01	POPPET STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	FLUID RESTRICTION IN BOTH DIRECTIONS	L.E. FLAPS MOVE SLOWLY DURING RETRACTION	OPERATIONAL CHECKS	-----	135 185 170	III	34.7	0.19	0.50	3.29
		07.031-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	FLUID RESTRICTION	POSSIBLE LOSS OF L.E. FLAP CONTROL	OPERATIONAL CHECKS	-----	185 306	II		0.11	0.50	1.91
		07.031-03	CRACKED HOUSING/ PORT;SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; PRESSURE INDICATOR	-----	190 690 381	II		0.70	0.10	2.43
LEADING EDGE FLAP RESTRICTOR - TWO WAY (4)	LIMITS PISTON SPEED DURING EXTENSION & RETRACTION	07.032-01	POPPET STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	FLUID RESTRICTION IN BOTH DIRECTIONS	L.E. FLAPS MOVE SLOWLY DURING RETRACTION	OPERATIONAL CHECKS	-----	135 185 170	III	34.7	0.19	0.50	3.30
		07.032-02	VALVE CLOGGED	CONTAMINANTS/ DIRT	FLUID RESTRICTION	POSSIBLE LOSS OF L.E. FLAP CONTROL	OPERATIONAL CHECKS	-----	185 306	II		0.11	0.50	1.91
		07.032-03	CRACKED HOUSING/ PORT;SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID; PRESSURE INDICATOR	-----	190 690 381	II		0.70	0.10	2.43
LEADING EDGE FLAP COILED TUBING - OUTBOARD & CENTER SECTION PRESS. & RET. (16)	PROVIDES FLEXIBLE FLUID CONNECTION TO LEADING EDGE FLAP ACTUATORS	07.041-01 07.043-01	CRACKED TUBING/ LEAKING FITTINGS	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	070 190 381	II	106.5	1.00	0.60	63.90
LEADING EDGE FLAP SOLENOID SELECTOR VALVE	PORTS FLUID TO L.E. FLAP ACTUATORS UPON DIRECTIONAL COMMAND	07.085-01	MALFUNCTIONING/ INOPERATIVE	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO FOLLOW COMMAND	LOSS OF L.E. FLAP CONTROL	NO ACTUATOR RESPONSE; OPERATIONAL CHECKS	-----	135 306	II	15.1	0.30	0.40	1.81

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LEADING EDGE FLAP SOLENOID SELECTOR VALVE (CONTINUED)	PORTS FLUID TO L.E. FLAP ACTUATORS UPON DIRECTIONAL COMMAND	07.085-02	VALVE LEAKING	WEAK/FAILED SEAL	POSSIBLE FLUID EROSION	POWER LOSS; POSSIBLE FLUID OVERHEATING	NONE	-----	185 306	III		0.60	0.50	4.53
		07.085-03	CRACKED HOUSING/ FITTINGS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.10	0.10	0.15
LEADING EDGE (L.E.) FLAP ACTUATOR (6)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF L.E. FLAPS	07-108-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 306 381	II	40.2	0.40	0.10	1.61
		07-108-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.02	0.50	0.40
		07-108-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	REDUNDANT ACTUATOR	185 520 935 170	II		0.11	0.10	0.44
		07-108-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE	POSSIBLE CHANGE IN EXTEND/RETRACT TIMES	ACTUATOR PERFORMANCE CHECKS	REDUNDANT ACTUATOR	020 306 381	III		0.15	0.30	1.81
		07-108-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL/ EXTERNAL DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE; CYLINDER BORE SCORING/ BINDING	POSSIBLE ROUGH OPERATION	ACTUATOR PERFORMANCE CHECKS	REDUNDANT ACTUATOR	190 935 780 381	III		0.01	0.30	0.12
		07-108-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ CONTAMINATION	INCREASED PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	REDUNDANT ACTUATOR	520 935 170 185	IV		0.01	0.00	0.00
		07-108-07	CRACKED HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	190 690 381	II		0.15	0.10	0.60
		07-108-08	SPRING FAILURE	INTERNAL DAMAGE/ FATIGUE	FINGERS WILL NOT LOCK ACTUATOR IN A RETRACT/EXTEND POSITION	AFFECTED L.E. FLAP CANNOT BE LOCKED IN RETRACT/EXTEND POSITION	ACTUATOR PERFORMANCE CHECKS	REDUNDANT ACTUATOR	070 780	II		0.03	0.60	0.72

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY λ_p	α	β	λ_o
LEADING EDGE (L.E.) FLAP ACTUATOR (6) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF L.E. FLAPS	07-108-09	DAMAGED MICRO SWITCH	FATIGUE/ INTERNAL DAMAGE/ CORROSION	NONE	FALSE INDICATION TO PILOT ABOUT POSITION OF FLAPS	ACTUATOR PERFORMANCE CHECKS	-----	070 170	III		0.08	0.20	0.64
RUDDER SYSTEM CHECK VALVE - FC-1/FC-2 PRESSURE (2)	HOLDS RUDDER IN FIXED POSITION IN CASE OF TWO SYSTEM FAILURE	10.044-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	NONE	NONE	FC-1/FC-2 SUBSYSTEM	135 366	IV	6.7	0.10	0.50	0.34
		10.044-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	LOSS OF RUDDER CONTROL	RUDDER PERFORMANCE CHECKS	FC-1/FC-2 SUBSYSTEM	135 185 170	II		0.10	0.50	0.34
		10.044-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
RUDDER ACTUATOR	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF RUDDER CONTROL SURFACE	10-103-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 306 381	II	298.4	0.24	0.10	7.16
		10-103-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.04	0.50	5.97
		10-103-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	185 520 935 170	II		0.17	0.10	5.07
		10-103-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE	NONE	ACTUATOR DISASSEMBLY	DUAL TANDEM CYLINDER	020 306 381	IV		0.12	0.00	0.00
		10-103-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL/ EXTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE/ BINDING	POSSIBLE ROUGH OPERATION	POOR ACTUATOR RESPONSE	DUAL TANDEM CYLINDER	190 935 780 381	III		0.16	0.20	9.55

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY λ_p	α	β	λ_o
RUDDER ACTUATOR (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF RUDDER CONTROL SURFACE	10-103-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ CONTAMINATION	INCREASED PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	DUAL TANDEM CYLINDER	520 935 170 185	IV		0.05	0.00	0.00
		10-103-07	CRACKED HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID ; LOSS OF BOTH FC SYSTEMS IF CRACK PROPAGATES ACROSS PARTITION	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	I		0.22	0.10	6.56
RUDDER ACTUATOR SERVO VALVE	CONTROLS POSITIONING OF RUDDER ACTUATOR	10.109-01	VALVE STUCK AT NULL	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	LOSS OF RUDDER CONTROL	RUDDER PERFORMANCE CHECKS	ROLL CONTROL	135 306	II	257.5	0.10	0.20	5.15
		10.109-02	VALVE STUCK HARD OVER	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	LOSS OF RUDDER CONTROL; ACTUATOR HARD OVER	RUDDER PERFORMANCE CHECKS	ROLL CONTROL	135 185 170	II		0.10	0.20	5.15
		10.109-03	VALVE CLOGGED	CONTAMINANTS/ DIRT	REDUCED FLUID FLOW THROUGH VALVE	REDUCED ACTUATOR RATES	RUDDER PERFORMANCE CHECKS	ROLL CONTROL	185 306	III		0.10	0.40	10.30
		10.109-04	CRACKED HOUSING/ FAILED SEALS	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.70	0.10	18.03
UNIT HORIZONTAL TAIL (UHT) SYSTEM CHECK VALVE - FC-1,FC2 PRESSURE (2)	HOLDS UHT IN FIXED POSITION IN CASE OF TWO SYSTEM FAILURE	11.046-01	VALVE STUCK OPEN	INTERNAL DAMAGE/ DIRT	VALVE FAILS TO CLOSE	NONE	NONE	FC-1 SUBSYSTEM	135 306	IV	6.7	0.10	0.00	0.00
		11.046-02	VALVE STUCK CLOSED	CONTAMINANTS/ CORROSION/ INTERNAL DAMAGE	VALVE FAILS TO OPEN	LOSS OF UHT CONTROL	UHT PERFORMANCE CHECKS	FC-1 SUBSYSTEM	135 185 170	II		0.10	0.70	0.47
		11.046-03	CRACKED HOUSING/ SEAL FAILURE	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1 SUBSYSTEM	190 690 381	II		0.80	0.10	0.54
UNIT HORIZONTAL TAIL (UHT) ACTUATOR (2)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF UHT SURFACES	11-104-01	DAMAGED ROD SEAL	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	TWO STAGE ROD SEALS	020 306 381	II	290.0	0.09	0.10	2.61

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
UNIT HORIZONTAL TAIL (UHT) ACTUATOR (2) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF UHT SURFACES	11-104-02	BENT PISTON ROD	FATIGUE/EXTERNAL FORCE	CYLINDER BINDING	ROUGH EXTENSION/ RETRACTION	ACTUATOR PERFORMANCE CHECKS	-----	135 780	III		0.03	0.60	5.22
		11-104-03	SCORED/PITTED PISTON ROD	CONTAMINATION/ WEAR/CORROSION	INCREASED ROD SEAL WEAR; POSSIBLE EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	-----	185 520 935 170	II		0.06	0.10	1.74
		11-104-04	DAMAGED PISTON SEAL/GLAND	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	POSSIBLE INTERNAL LEAKAGE	NONE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	020 304 381	IV		0.05	0.00	0.00
		11-104-05	CRACKED/SCORED/ DISTORTED PISTON	FATIGUE/INTERNAL/ EXTERNAL DAMAGE/ CONTAMINATION	INTERNAL LEAKAGE/ BINDING	POSSIBLE ROUGH OPERATION	POOR ACTUATOR RESPONSE	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	190 935 780 381	III		0.04	0.30	3.48
		11-104-06	SCORED/PITTED CYLINDER WALL	CORROSION/WEAR/ CONTAMINATION	INCREASED PISTON SEAL WEAR	NONE	ACTUATOR DISASSEMBLY	FC-1/FC-2 SUBSYSTEM; DUAL TANDEM CYLINDER	520 935 170 185	IV		0.03	0.00	0.00
		11-104-07	CRACKED ACTUATOR HOUSING/CAP/ CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID ; LOSS OF BOTH FC SYSTEMS IF CRACK PROPAGATES ACROSS PARTITION	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	I		0.08	0.10	2.32
		11-104-08	DAMAGED ACTUATOR ARM	FATIGUE/BINDING/ EXTERNAL DAMAGE	SERVO VALVE INOPERATIVE	NO UHT ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	I		0.04	0.40	4.64
		11-104-09	DAMAGED PRELOAD SPRING ASSEMBLY	FATIGUE/ EXTERNAL DAMAGE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN PERFORMANCE	ACTUATOR PERFORM. CHECKS	-----	135 780	IV		0.03	0.30	2.61
		11-104-10	DAMAGED SPOOL ROD SEAL IN SERVO VALVE	NIBBLING/WEAR/ DETERIORATION/ INSTALLATION DAMAGE/ CONTAMINATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	020 306 381	II		0.09	0.10	2.61
		11-104-11	BENT SERVO VALVE SPOOL ROD	FATIGUE/EXTERNAL FORCE	SPOOL BINDING	POOR OR NO UHT ACTUATOR RESPONSE	ACTUATOR PERFORM. CHECKS	-----	135 780	III		0.02	0.40	2.32

LHS FAILURE MODE AND EFFECT ANALYSIS

IDENTIFICATION	FUNCTION	I.D. NUMBER	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECT: LOCAL EFFECTS	FAILURE EFFECT: END RESULTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	MALF CODE	SEVR LEVL	LOSS FREQUENCY: λ_p	α	β	λ_o
UNIT HORIZONTAL TAIL (UHT) ACTUATOR (2) (CONTINUED)	CONVERT FLUID ENERGY INTO MECHANICAL MOVEMENT OF UHT SURFACES	11-104-12	SCORED/PITTED SERVO VALVE SPOOL ROD	CORROSION/WEAR/ CONTAMINATION	INCREASED ROD SEAL WEAR	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	DUAL TANDEM CYLINDER	170 185 935 520	II		0.07	0.10	2.03
		11-104-13	DAMAGED SEALS ON SERVO VALVE SLEEVE	NIBBLING/WEAR/ INSTALLATION DAMAGE/ CONTAMINATION	INTERNAL/EXTERNAL LEAKAGE	POSSIBLE LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID/ ACTUATOR DISASSEMBLY	DUAL TANDEM CYLINDER	020 185 381	II		0.06	0.10	1.74
		11-104-14	WORN/SCORED/SERVO VALVE SPOOL METERING EDGES	CONTAMINATION/ EROSION/CORROSION	INCREASED INTERNAL LEAKAGE	INCREASED POWER LOSS	ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	170 185 935 020	II		0.05	0.40	5.80
		11-104-15	CRACKED SERVO VALVE HOUSING/ CAP/CONNECTOR	FATIGUE/ VIBRATION/ EXTERNAL DAMAGE	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381	II		0.08	0.10	2.32
		11-104-16	DAMAGED SERVO VALVE PRELOAD SPRING	FATIGUE/DAMAGED SPRING GUIDE	FREE-PLAY IN MECHANICAL JOINTS	SLIGHT DEGRADATION IN ACTUATOR PERFORMANCE	ACTUATOR PERFORMANCE CHECKS	DUAL TANDEM CYLINDER	135 780	IV		0.03	0.40	3.48
		11-104-17	SERVO VALVE/ ACTUATOR CONNECTOR DAMAGE/ CRACKING	FATIGUE/ VIBRATION/ CORROSION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381 170	II		0.08	0.10	2.32
TUBING/FITTINGS (TOTAL SYSTEM)	PROVIDES PATH/ CONNECTIONS FOR SYSTEM FLUID	-----	CRACKED/BROKEN	FATIGUE/ VIBRATION	EXTERNAL LEAKAGE	LOSS OF SYSTEM FLUID	VISIBLE LOSS OF FLUID	FC-1/FC-2 SUBSYSTEM	190 690 381 170	II	721.5	1.00	0.10	72.15

APPENDIX G

LHS SPECIFICATIONS

General Specifications	
LHS-8800 REV A	Hydraulic System Aircraft, 8000 PSI, Design and Installation Requirements for, dated 15 August 1985
LHS-8801 REV A	Hydraulic System Components, 8000 PSI, Aircraft, General Specification for, dated 15 August 1985
Component Specifications	
LHS-8810 REV A	Pumps, Hydraulic, Variable Delivery, 8000 PSI, dated 15 August 1985
LHS-8811	Accumulators, Hydraulic, Cylindrical, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8812 REV A	Cylinders, Hydraulic, 8000 PSI, dated 15 August 1985
LHS-8813	Valves, Aircraft Power Brake, 8000 PSI, dated 15 July 1980
LHS-8814	Valves, Check, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8815 REV A	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 5 Micron Absolute, 8000 PSI, dated 15 August 1985
LHS-8816 REV A	Fittings, Fluid Connection, Aircraft, 8000 PSI, dated 15 August 1985
LHS-8817	Valve; Aircraft Hydraulic Flow Regulator, 8000 PSI, dated 2 July 1980
LHS-8818 REV A	Hose Assemblies, Hydraulic, 8000 PSI, Aircraft, dated 15 August 1985
LHS-8819	Motors, Aircraft Hydraulic, Constant Displacement, 8000 PSI, dated 7 August 1980
LHS-8821 REV A	Gland Design; Seals, Hydraulic, 8000 PSI, dated 15 August 1985
LHS-8822	Gage, Pressure, Dial Indicating, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8823	Valve; Aircraft Hydraulic Pressure Reducer, 8000 PSI, dated 1 July 1980
LHS-8824	Snubber, Hydraulic Pressure, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8825	Pressure Switch, Aircraft, Hydraulic, 8000 PSI, dated 23 July 1980

LHS-8826	Transmitter, Pressure, Hydraulic, 8000 PSI, Aircraft, dated 24 June 1980
LHS-8827	Valve; Aircraft Hydraulic Priority, 8000 PSI, dated 28 July 1980
LHS-8828 REV A	Coupling, Quick Disconnect, Self-Sealing, Hydraulic, 8000 PSI, Aircraft, dated 15 August 1985
LHS-8829	Valve, Hydraulic Pressure Relief, 8000 PSI, Aircraft, dated 19 June 1980
LHS-8830	Reservoirs; Aircraft, Hydraulic Separated Type, dated 19 June 1980
LHS-8831	Restrictor, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8833	Valve, Bleed, Hydraulic, 8000 PSI, Aircraft, dated 18 August 1980
LHS-8834	Valve, Direct Drive, Electro-hydraulic, Servo Control, 8000 PSI, Aircra t, dated 19 August 1980
LHS-8835	Valve, Aircraft Hydraulic Directional Control, Rotary Selector, 8000 PSI, dated 15 August 1980
LHS-8836	Valve, Shuttle, Hydraulic, 8000 PSI, Aircraft, dated 28 August 1980
LHS-8837 REV A	Valve, Hydraulic Control, Solenoid Operated, 8000 PSI, Aircraft, dated 15 August 1985
LHS-8838	Joint, Swivel, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8839	Tubing, Steel, Corrosion Resistant (21-6-9), Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8842	Tubing, 3AL-2.5V Titanium Alloy, Hydraulic, 8000 PSI, Aircraft, dated 15 August 1985

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APPENDIX H

BLACK RESIDUE INVESTIGATION

Scientific & Laboratory Services Dept. October 28, 1985

Telecopy

To: Mr. William Bickel
Mr. Robert Hanning
North American Aircraft Division
Rockwell International, Columbus, Ohio
Telecopy No.: (614) 239-4300

cc: E. Kirnbauer
G. Bishop
G. Dow
W. Needelman
C. Sun
SLS Proj. Files: H1215, H1275, H1635, H1656

From: Daniel R. Uhr, Jr., Ph.D.
Staff Scientist
Pall Corporation
Scientific and Laboratory Services Depart.
Glen Cove, New York

Subject: Summary of Results and Conclusions Regarding the Analysis of Composition of "Black Residue" and Results of Recent Contamination Analyses Conducted on Samples of MIL-H-83282 from the Prototype 8,000 psi Lightweight Hydraulic System (LHS).

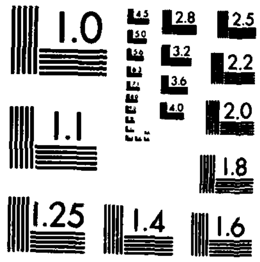
I. Results of Elemental Analysis of Particles Contributing to "Black Residue" and APM Filter Location Where Particle Type Was Found in Largest Amount

Black Particle Type	XES[1] Elemental Analyses	Found Most In Filter Location
A	Organic particles (i.e. no response to XES)	pressure-line
B	major aluminum; minor sulfur; traces of chromium and zinc	pressure-line
C	major iron; trace of chromium	case drain
D	major chromium	return-line

[1] XES - X-ray fluorescent emission spectroscopy.

Note: Black particle types C and D were dark under oblique lighting and reflective under perpendicular lighting.

AD-A169 884 FABRICATION AND TESTING OF LIGHTWEIGHT HYDRAULIC SYSTEM 4/4
SIMULATOR HARDWAR..(U) ROCKWELL INTERNATIONAL COLUMBUS
OH NORTH AMERICAN AIRCRAFT OP.. W N BICKEL ET AL.
UNCLASSIFIED JAN 86 NA-85-0134 NADC-79024-60 F/G 13/7 NL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3.2
3.6
4.0
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2.0
1.1
1.8
1.25
1.4
1.6

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II. Analysis of "Black Residue" Particle Size Range and Percent of Black Particles in Collection of Particles From Filter Locations

Note: Data is presented for two system configurations. Fluid samples from the filter bowl were used as the source of particles for comparison. See attached System Configurations I and II.

	Pressure-line		Return-line		Case Drain	
System	% by No.	Micron Size Range	% by No.	Micron Size Range	% by No.	Micron Size Range
Configuration I	67	1 to 120	41	1 to 300	73	1 to 120
Configuration II	54	1 to 200	48	1 to 350	60	1 to 350

III. Particle Count Data on Fluid Samples Submitted in June 1985 re. 600 Hour Test, Rockwell LHS with APM (5 micron absolute) Filtration

Fluid Sample Designation(2)	~NAS 1638 Class(1)	No. of particles per milliliter(3) 1-5u	5-15u	15-25u	25-50u	50-100u	>100u
1) FC-1 (No. 1)	~Class 3	618	252	71	68	15	3.5
2) FC-1 (No. 2)	~Class 1	45	20	7	3	2	1
3) FC-2 (No. 1)	~Class 1	26	42	23	7	1	0.3
4) FC-2 (No. 2)	~Class 0	45	26	13	3	1	0.4
5) Reservoir,LHS	~Class 0	436	51	8	2	0.7	0.3

Note: 1) ~NAS 1638 Class is determined here based on particle size range larger than 5 microns and highest particle count for each sample.

2) APM 5 micron absolute filtration is employed in this system in pressure-line, return-line and case drain locations.

3) Particle Counting - Method - SAE ARP-598A.

IV. Results of Elemental Analysis of Seal Debris from Rockwell LHS Actuator, Submitted June 1985

The gelatinous material was analyzed by XES and found to contain silicon, chlorine and chromium.

Scientific & Laboratory Services Dept.

V. Results of Miscellaneous Analyses on the LHS Reservoir Fluid Sample Submitted June 1985

A. Gravimetric Analysis (Method ARP-785)

-Membrane - 0.2 um
-Solvent - Freon

Results: 2.0 mg/liter of particulate

B. Total Water (Method - Karl Fischer per DIN51-777)

Results: 134 ppm H_2O

Comments

1) The data reported in this Telecopy is to be included in a final comprehensive report of all useful data generated on samples submitted from two years of assistance on this project.

2) The results of analysis provided in this telecopy shows that "black residue" is a composite of four particle types. Organic black particles (A) are most numerous (i.e. contain no element heavier than sodium). Aluminum containing black particles (B) are completely black and not distinguishable from organic particles when examined microscopically.

Iron containing particles (C) and chromium containing particles (D) have a black appearance when viewed under an oblique (<90°) light source. Therefore, it is estimated that the later two particle types (C and D) contribute significantly to the black appearance of filtered particles. The case drain filters held a predominance of iron containing particles. The return-line filters held a large number of chromium containing particles.

Organic and aluminum containing particles were found in greatest number on the pressure-line filter.

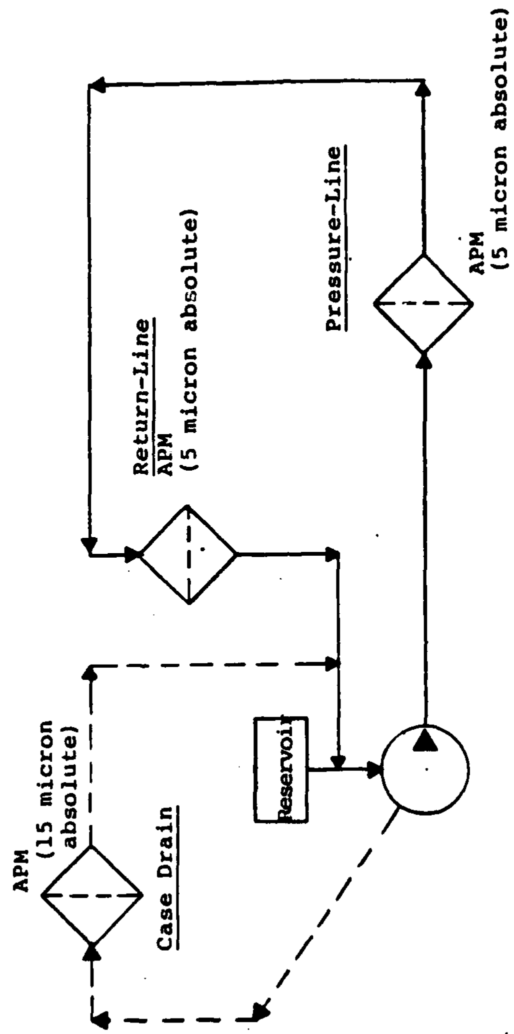
3) The results of particle counting fluid samples from the LHS FC-1 and FC-2 hydraulic loops show that APM, 5 micron absolute filtration is maintaining particulate contamination at levels represented by NAS 1638 Class 1 or cleaner. It is believed that sample 1 (i.e. FC-1, No. 1) is not representative of the rest of the samples collected. Excess contaminants may have been introduced into sample 1 during the sampling procedure.

Daniel R. Uhr, Jr.

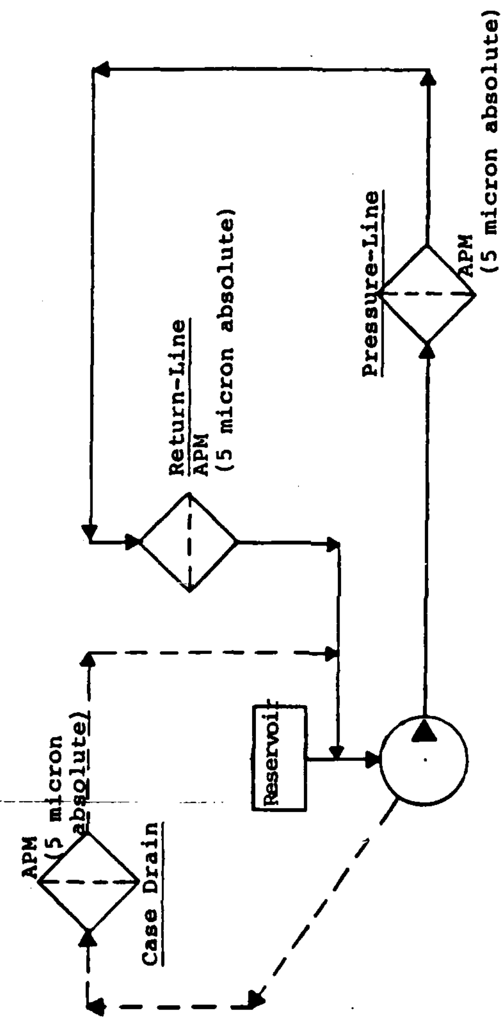
Daniel R. Uhr, Jr., Ph.D.
Staff Scientist

DRU:kmg

SYSTEM CONFIGURATION I



SYSTEM CONFIGURATION II



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